Three Essays on Gas Market Liberalization

DISSERTATION

zur Erlangung des akademischen Grades
Doctor rerum politicarum
(Doktor der Wirtschaftswissenschaft)

eingereicht an der

Wirtschaftswissenschaftlichen Fakultät
der Humboldt-Universität zu Berlin

von

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Tag des Kolloqiums: 07.05.2015

Acknowledgements

Words cannot express how grateful I am to Prof. Dr. Franz Hubert for his wise supervision and kindness, for patience in reading the numerous drafts and for the generous support. During all this time I could always come with any question to Prof. Hubert, and he always discussed a problem with me and gave excellent advice. I am deeply indebted to Prof. Hubert, without whose knowledge and enthusiasm this work would be impossible. I am grateful to Prof. Dr. Christian von Hirschhausen for his valuable comments at the annual meeting of the Verein für Socialpolitik.

I am thankful to Johannes H. Reijnierse for providing us with MATLAB code for calculating the nucleolus. I also thank Onur Cobanli for his collaboration. The papers presented in this dissertation benefited from comments of seminar participants of a number of conferences, e.g. European Association for Research in Industrial Economics Conference (2012), Verein für Socialpolitik Conference (2012, 2014), UECE Lisbon Meetings Conference (2014).

I am grateful to my parents and my brother, to my relatives and my dear friends for their support and belief in me.

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Introduction

This thesis consists of three essays two of which analyze the impact of liberalization of access to pipelines in natural gas markets within EU on the power of involved market players. The third essay is devoted to the analysis of methodological issues. Before giving a brief overview of all three essays, we decribe the main steps of liberalization process.

Liberalization of EU gas markets

Until 1990s the natural gas markets of EU Member States were typically characterized by the presence of vertically integrated 'national champions' such as GdF in France and ENI in Italy. The champions controlled imports, domestic production in a region, transmission and distribution networks. The Treaty establishing the European Community guarantees the free movement of goods, persons, services and capital. To provide these freedoms and to create a common market that will ensure the energy security, the EU Commission started liberalization of the European gas industry. The very first step of liberalization process was undertaken in the early nineties with the Council Directive 91/296/EEC on the transit of natural gas through grids (EU (1991)) and the Council Directive 90/377/EEC concerning a Community procedure to improve the transparency of gas and electricity prices charged to industrial end-users (EU (1990)). Several years later, in 1998, the Commission issued Directive 98/30/EC which is usually referred to as the First Gas Directive. This document settled the main principles of liberalization such as market opening and provision of non-discriminatory access to the transmission and distribution systems. According to Directive 98/30/EC, market opening had to be introduced initially for the large users of gas. The document presented a schedule of how the degree of market opening had to evolve over time. To provide non-discriminatory access to the networks, the Commission introduced the models of negotiated and regulated third-party access. The Member States had to comply with the First Gas Directive by 10 August 2000. Many of the requirements presented in this directive were later changed. Still, the document laid the basis for the gradual development of the liberalization process. In the words of Stern, ”the value of the directive, therefore, lies not so much in its specific provisions, which are likely to be rapidly overtaken by events, but rather in the fact that it established both the principle of access to (pipeline) networks, and the assurance that opponents of competition and liberalisation cannot indefinitely procrastinate in the opening up of their gas markets”.[1]

The implementation of the First Gas Directive and its impact on markets has been evaluated in several dimensions. The degree of market opening, price differences between countries, switching activity of customers and dynamics of new entries into the markets might be considered as indicators of the progress towards internal market. In December 2001 the Commission issued the ”first benchmarking report on the implementation of the internal electricity and gas market”. Though some Member States opened their markets on a larger scale than it was initially required by the First Gas Directive, the Commission considered the declared market opening in the year 2000 as satisfactory only for Germany and the UK.[2] The UK with the liberalized market performed extremely well with respect to all indicators. The level of market opening in other countries was evaluated as the obstacle for competition. However, the schedule of market opening was considered as satisfactory for almost all countries as they intended to achieve the full market opening till 2008 at the latest. Only Denmark and France did not announce the date of the full market opening which was perceived as a bad signal by the Commission.[3] Comparing the implementation of the reform across EU, Arentsen (2004) emphasized that the data presented in the report of the Commission ”reflect the legal positions of the Member States on market opening” and ”should not be read as real market opening”.[4] The first benchmarking report presented also evidence of switching activity among eligible customers. Except for the UK and to some extent for the Netherlands, the Commission found the overall progress in switching to be rather slow.[5] The same was observed for entry dynamics. New entrants tended to be incumbents of other Member States and the ”proportion of gas transported by the third-party

[1] Stern (1998), p. 18.

[2] Commission (2001), Commission (2000).

[3] Commission (2001), Table 3, p. 5.

[4] Arentsen (2004), p. 78.

[5] Commission (2001), Table 4, p. 116.

access" was rather modest.[6] In October 2002 the Commission issued the second benchmarking report. Some further progress was observed in market opening and switching activity. Nevertheless, the switching levels continued to be limited. The analysis of price changes showed that prices remained dispersed between Member States. There were almost as many cases when the prices for large users increased as when they reduced after the directive came into force.[7] Reviewing the progress in opening of natural gas markets, Newbery (2001) pointed out the importance of regulated third-party access for the achievement of the Commission's goals.

To accelerate the liberalization process, the Commission issued Directive 2003/55/EC or the Second Gas Directive in the year 2003. Main modifications referred to the rules concerning market opening and provision of non-discriminatory access to the networks. With Directive 2003/55/EC all non-household customers had to become eligible from July 2004 and all customers had to be able to buy gas from supplier of their choice from July 2007. So that full market opening was introduced. The Commission stressed the importance of fair access to the networks for achievement of the common market. According to the Second Gas Directive, the access to the system had to be organised only by using the model of regulated third-party access based on published tarrifs. To eliminate the possibility of network operators to discriminate between system users, the Commission required unbundling of operators from the vertically integrated gas structures. Directive 2003/55/EC did not require ownership unbundling. Transmission system operators (TSOs) and distribution system operators (DSOs) had to become independent at least in terms of "legal form, organisation and decision making".[8] The document settled the same requirements for both types of operators. The only difference in requirements referred to the time frames. The Commission required legal and functional unbundling of TSOs from July 2004. The functional unbundling of DSOs was required from July 2004. The deadline for legal unbundling of DSOs was settled to July 2007, when all customers had to become eligible according to the Second Gas Directive.

Though the acceleration directive was introduced, the Commission continued to report indicators of slow progress towards internal market. For most of the coun-

[6] Commission (2001), Table 4, p. 21.

[7] Commission (2002), Table 4, p. 6.

[8] EU (2003), Article 9(1) and Article 13(1).

tries cumulative switching rates since market opening were less than 50%.[9] The lack of market integration was depicted in slow convergence of prices.[10] Neumann et al. (2006) provided evidence of insufficient integration of the continental markets. The authors analyzed the convergence of prices for three trading hubs: the 'NBP' in the UK, 'Zeebrugge' in Belgium and 'Bunde' in Germany. The daily day-ahead bid prices from March 2000 until February 2005 were used in the analysis. While finding evidence of strong convergence for the pair the NBP and Zeebrugge, the authors did not observe any price convergence for the pair Zeebrugge and Bunde. Robinson (2007) presented controversial results for the convergence of retail prices. The author conducted an econometric analysis of convergence of annual retail gas prices for six countries for the period from 1978 to 2003 using three tests. For this period the convergence hypothesis was not rejected for 2 tests. Results of the third test do not support the hypothesis.

There are also studies devoted to an econometric analysis of the effect of liberalization on prices. Copenhagen Economics (2005) estimated the impact of liberalization on industrial prices across 15 European countries and found that liberalization decreased prices by 1% in the short-run. Ernst & Young (2006) also reported the decrease of industrial prices from liberalization. They found "evidence of a significant benefit on consumer prices from completing the full unbundling of the TSO".[11] Brau et al. (2010) estimated the impact of reform on household prices. The authors implemented analysis for the period from 1991 to 2007 for 15 European countries. Brau et al. (2010) used several reform indicators, e.g. indicators of the degree of vertical integration and public ownership.[12] The estimates present a minor impact of indicators on prices. The interesting result is that the variable 'vertical integration' is never significant. Haase and Bressers (2010) discussed the obstacles for estimation of the effect of "regulation-for-competition" on the natural gas prices (e.g. linkage to the oil prices). Overall, the authors pointed to the lack of empirical research studying the impact of regulation on the economic perfomance of natural gas industry. Booz & Company et al. (2013) also stress the lack of empirical research in their literature survey and emphasize that existing studies are controversial with respect to the results.[13]

[9] Commission (2005), Table 3.2, p. 39.

[10] Commission (2005), p. 20.

[11] Ernst & Young (2006), p. 36.

[12] Brau et al. (2010), p. 3.

[13] Booz & Company et al. (2013), p. 10.

In addition to the annual report, in 2005 the Commission started a Sector Inquiry that revealed a number of shortcomings in the previous legislation. The Commission presented numerous examples of discriminatory behavior of TSOs, e.g. charging of different transportation tariffs from the affiliated and non-affiliated users. The scope for discrimination existed because of insufficient unbundling of networks. The problem is that in the Second Gas Directive the Commission tried to ensure that TSOs "act independently from the incentives of the vertically integrated group", but the document did not remove incentives of national champions to discriminate.[14] From the Commission's point of view, the importance of the proper unbundling of networks was stressed by evidence of the favourable impact of ownership unbundled TSOs on prices.[15] In contrast, most champions were against ownership unbundling. The champions questioned the favourable impact and pointed out that ownership unbundling was implemented in countries with large domestic production.[16]

To overcome the flaws of the Second Gas Directive, the Commission issued Directive 2009/73/EC which refers to the Third Energy Package.[17] Directive 2009/73/EC introduced stricter rules for unbundling of operators in order to avoid discriminatory behavior. Member States could choose ownership unbundling of TSOs or choose between the models of independent system operator or independent transmission operator. The requirements for unbundling of DSOs remained almost the same as in Directive 2003/55/EC. Additional rules referred to the regulation procedure. The reason is that at the time the Sector Inquiry was conducted, the impact of the unbundling of DSOs could not be fully studied due to the time frames defined by the Second Gas Directive.

Liberalization of access to pipelines is aimed to boost the entry into the natural gas industry and to create a competitive market. This process is perceived differently by various stakeholders. Non-incumbent stakeholders consider the market dominance of champions and vertical integration of activities throughout the supply chain as the sources of high prices.[18] Incumbents point out the high concentration

[14]Commission (2007b), First Phase, p. 57.

[15]Commission (2008), p. 5.

[16]Commission (2007b), Second Phase, p. 211.

[17]The Third Energy Package includes also Regulation (EC) No 715/2009 that requires establishment of the European Network of Transmission System Operators for Gas (ENTSOG) and defines its tasks (EU (2009b)).

[18]Commission (2007b), Second Phase, p. 206.

of producers in the upstream market outside EU and the strong dependence of EU on imports from these outside suppliers. So that incumbents argue for a "limited number of strong market players in the industry".[19] Not only champions, but also the researchers stress possible negative consequences of liberalization. For example, Austvik (2009) discusses a conflict between the "consumers' short- and long-terms interests".[20] Resulting in lower and more volatile prices in the short-term, the liberalization might lead to a delay of "investments in new production capacity".[21] In the long-term this will result in a decrease of supply and higher prices, because natural gas is a non-renewable resource and it takes time to develop a new gas field. Therefore, the author calls for caution in implementing the reform and emphasizes the importance of gradual market opening required in Directive 2003/55/EC.

We are interested in the question of whether national champions can create countervailing power against external producers. Another question we are interested in is at the expense of which players consumers in EU could gain. It is important to note that before the liberalization process champions had the role of middlemen between customers within EU and producers outside EU. Opening of access to pipelines eliminates this role of champions. Economic intuition suggests that the customers and producers will reap the benefits of such a step, but it is unclear how they will share the gains.

Common framework

To study the impact of liberalization on the power of market players, we develop a disaggregated model of the Eurasian natural gas supply system. We model the Eurasian gas network as the set of nodes and links. Overall, the network is represented by 83 links and 66 nodes. The set of nodes includes different types of nodes such as production, transit and consumption nodes. The set of links consists of onedirectional links such as production and consumption links and bidirectional transit links. The set of nodes differs from the set of strategic players. The nodes represent the endpoints of the links. The players have access to parts of the network and are needed for the access to the links. For example, the player 'Belarus' has access to production and consumption links in Belarus and is needed for access to the pipes between Belarus and Poland and between Belarus and Russia.

[19] Commission (2007b), Second Phase, p. 207.

[20] Austvik (2009), p. 99.

[21] Austvik (2009), p. 99.

We consider four main exporters of pipeline gas to Europe (Russia, Norway, Algeria and Libya) and two main transit countries for Russian gas (Belarus and Ukraine). Within EU we aggregate some countries into regions (e.g. Spain and Portugal are aggregated into 'SpainPort' region) and consider also separate countries (e.g. Italy, Belgium). We include Turkey into the geographical scope and take into account gas flows from the Caspian region.

We model interdependenices among the players in the Eurasian gas network as a cooperative game for which we consider various solutions: the Shapley value, the nucleolus and the core. To obtain the value function we have to solve a constrained maximization problem for each coalition. We maximize the joint surplus of players in a coalition with respect to the gas flows in available pipelines subject to a number of constraints. For the purpose of our research, in the first essay we consider 17 players and, hence, 131 072 coalitions. In the second and third essays we work with 20 players and, hence, with 1 048 576 coalitions. Essential part of the research is the development an algorithm to solve the optimization problem fast and efficiently.

Liberalization represents a change of access rights. Before the reform, an owner of pipeline can arbitrary restrict the access to it. With liberalization the owner has to grant third-party access on a cost base. So that the owner cannot derive bargaining power from denying the access. We model liberalization by changing the set of players who are needed for the access to a pipeline. For example, before liberalization, in order the link between Belarus and Poland to be available for a coalition, both Belarus and Poland have to be in the coalition. If access to the transmission networks is liberalized, then only Belarus is needed for the access to this link.

To calibrate our theoretical model we use data on consumption and flows between the regions. Since all three essays are built on one calibrated network model, we present one technical documentation on the programming packages in the end of this thesis. The documentation includes the description of all steps taken to conduct the calculations and to receive the results. The programming packages were written in `Wolfram Mathematica` and in `MATLAB`. The code is available online at `http://www.ms-hns.de/research_gas`. We thank Johannes H. Reijnierse for providing us with `MATLAB` code for calculating the nucleolus.

The essays

In the first paper we study the regional effects of liberalization of access to transmission networks within EU. Here we use only the Shapley value as a power index.

We focus on the redistribution of power between EU regions and external suppliers. Each EU region controls domestic production and access to local customers. So that we do not consider the impact of reform on the power of customers as compared to the power of champions within a region. Within this framework we also study incentives of outside producers for cartelization. We compare the gains from creating a cartel before and after opening of access to high-pressure pipelines. We also analyze the profitability of pairwise mergers within EU and consider the effect of centralized EU policy with respect to external gas relations.

In the second paper we consider the liberalization of access to transmission networks as the first step of reform and liberalization of access to distribution networks as the second step. We distinguish explicitly between a champion and a customer in a region. As the number of calculations increases fast in the number of players, we introduce a champion and a customer only for selected regions. These regions are 'Center-East', 'Center', 'South-West', Netherlands and Italy. As a result, the set of players includes regional champions and customers, some EU regions and players outside EU. Taking into account the second step of reform, we can estimate the effect of cutting out the middlemen between the customers and outside producers on the power of involved players. As an alternative to the Shapley value concept we also use the nucleolus which represents a unique point in the core. While robust with respect to parameters, the results of the model depend on the applied solution concept. This leads us to the analysis of the methodoligical issues of applying cooperative game theory.

In the third paper we continue to use the previous framework, but the focus is on the relation of the Shapley value and the nucleolus to the core. With respect to the application of the Shapley value we focus on the stability issue. For our gas network model the Shapley value is never in the core and, hence, not stable. To evaluate the degree of instability of a payoff allocation which is not in the core, we introduce several stability measures. We propose an extension of the strong ϵ-core, the $n\epsilon$-core, and consider three metrics to evaluate (in)stability. The first measure is given by the minimal costs of setting up a coalition which provide stability of the allocation for a given upper bound on the size of coalitions. The second metric refers to the minimal size of a blocking coalition for a given value of costs. The third measure is the fraction of deviating coalitions to the total number of coalitions for a given upper bound on the size of coalitions and for given costs. We apply all three measures to our real life model and study the impact of liberalization on the degree of instability of the Shapley value.

With respect to the nucleolus and the core, we study whether the change of nucleolus is a good indicator of the effect of liberalization on the core. First, we explore the effect of each step of reform on the core. We prove that liberalization consecutively compresses the core. We study the impact of liberalization on the minimal and maximal values achievable by players in the core and find the dominant effects. Then we discuss whether the impact on the nucleolus might be considered as the indicator of the shift of the core.

Chapter 1

Competition or Countervailing Power for the European Gas Market

This chapter is based on a joint paper with Franz Hubert.

Abstract

Heading towards a common market for natural gas, the EU Commission is trying to liberalize pipeline access, break up vertically integrated structures and foster competition between the regions. However, critics argue that strong national players are needed to counter the power of a small number of external gas suppliers, such as Russia, Norway and Algeria, on which the EU depends to satisfy more than half of its consumption. We model the European gas supply system as a cooperative game and use the Shapley value as a power index for the players. In accordance with the buyer power argument, we find that the liberalization of access to the high pressure pipeline system within the EU, on balance, *strengthens* the power of external suppliers and weakens the regions within EU. Though, there is considerable variety on both sides of the market.

Keywords: Bargaining Power, Network Access, Natural Gas
JEL class.: L1, L95

This paper is part of larger collaborative research project on the Eurasian gas network to which Onur Cobanli made essential contributions. The authors are thankful for helpful comments from seminar participants at meetings of EARIE, EcoMod and Verein für Socialpolitik.

1.1 Introduction

When the European Union formally established the common market in 1993, its gas sector was a fragmented industry, where state owned or heavily regulated "national champions", such as Gaz de France, Italian ENI, or German Ruhrgas, dominated local production and distribution as well as imports and long distance transport. As in telecommunications and electric power, the Commission initiated a policy to achieve integration and foster competition by opening access to bottleneck facilities such as transport pipelines and distribution networks.[22] However, critics of the Commission point to a fundamental flaw in its approach. In marked contrast to electric power, which is almost entirely produced within the Union, two third of its gas consumption is imported from a small number of producers beyond EU jurisdiction, whose stakes in transportation and distribution within the EU are negligible.[23] Gas importers, and often their governments, argue that strong national or even European players are needed to create "countervailing power" against gas exporting countries. In the words of France's former President Nicolas Sarkozy: "Without Gaz de France, who would stand up to Gazprom?" (quoted in Mortished (2007)). According to critics, by weakening the national champions, the Commission risks strengthening already powerful outside producers such as Russia, Algeria, and Norway, which together account for 85% of imports.

These opposing views on priorities in the gas sector also clashed in several merger cases. When German energy companies E.ON and Ruhrgas applied for merger in 2001, Bundeskartellamt, the German authority for merger control, declined approval arguing that it would give the company a dominant position in import, transport and distribution. While the German Monopoly Commission and the European Commission supported Bundeskartellamt's pro competitive stance, the German Government overruled the verdict. It claimed that the concentration is justified by

[22]The process started with Directive 98/30/EC (EU (1998)), later amended by the Directive 2003/55/EC (EU (2003)) concerning common rules for the internal market in natural gas and the Council Directive 2004/67/EC of 26 April 2004 concerning measures to safeguard security of natural gas supply (EU (2004)). Frustrated with slow progress the Commission introduced stricter rules for unbundling gas transport (see Directive 2009/73/EC (EU (2009a))).

[23]It is, in fact, surprising how little attention the Commission initially payed to Europe's import dependency in the gas sector. For example, in its explanatory memorandum on proposed amendments to the Directive 2003/55/EC, the Commission consistently speaks of an "electricity and gas market" both in the analytical statements as well as in its recommendations. The whole document fails to acknowledge any structural differences between the two sectors.

an overriding public interest, namely it would help to improve the security of supply of natural gas in Germany.[24] While the Commission could not block the German deal, it successfully prevented Italian ENI in cooperation with Portuguese power company EDP from taking over Portuguese gas operator GDP in 2004.

Concerns over producer power grew stronger in the years before the financial crisis. The foundation of the Gas Exporting Countries Forum 2001 in Teheran fueled worries that a gas cartel similar to the OPEC might be in the making. Later, rapidly increasing gas prices put ‘energy security’ on the top of the European agenda. Although most observers discount the chances for a strong gas cartel, the Commission began to move towards a centralization of the EU’s foreign energy relations. As a first step it obliged members to provide information about intergovernmental agreements with third countries that influence gas supplies in order to be able to assess “the security of supply at Union level”. The aim is to enhance coherence of the external energy policy eventually making it possible for EU to “speak with one voice”.[25]

In this paper we analyze a disaggregated model of the European gas supply system as a cooperative game and use the Shapley value as a power index for the players. Our focus is on the distribution of power between regions within EU and outside producers and how it is affected by institutional change. The starting point is a patchwork of local monopolies, each controlling access to production, distribution, and the trunk pipes in its respective region. First, we analyze the liberalization of access to the long distance transport system within the EU. This reform strips the local champions of the power derived from monopolizing transit and creates an integrated wholesale market. However, it falls short of creating a fully competitive market. National champions retain control of local production and local distribution, hence access to customers. Second, we look at mergers between two or more local champions, both in a fragmented and an integrated market. We also analyze the potential of centralized bargaining with outside suppliers through political coordination at the EU level.

We find that the liberalization of access to the high pressure pipeline system within the EU, on balance, *strengthens* the power of external suppliers and transit coun-

[24] See Bundeskartellamt (2002) and Bundesminister für Wirtschaft und Technologie (2002).

[25] On the gas cartel see Hallouche (2006), Finon (2007), and Gabriel et al. (2012). The groundwork for the Commission’s policy has been laid out in a series declarations EU (2010), Commission (2011a), Commission (2011b).

tries for Russian gas and weakens the regions within EU. There is, however, considerable variety on both sides of the market, which might explain some of the difficulties of implementing the reforms in the European Union. Surprisingly, while the integration of the wholesale market tends to strengthen outside producers, it reduces their possible gains from establishing a producer cartel.

Our results regarding mergers depend much on the market structure. In a fragmented wholesale market, pairwise mergers of 'national champions' tend to be profitable for the parties, but the impact on outside producers is rather mixed. Among pairwise mergers of EU regions, excluding Netherlands, which is the main producer within EU, we find almost as many cases where the bargaining power of outside producers as a group is enhanced, as cases where it is diminished. Hence, a fragmented market provides only little evidence in support of the view that it takes large European players to counter the power of outside producers. Once market integration is achieved, a number of pairwise mergers turn unprofitable, often because they increase the bargaining power of Russia and transit countries for Russian gas. Again excluding Netherlands, only few mergers involving the UK curb the power of all outside producers. Under both market structures, however, there are large gains to be obtained by full centralization at the EU level.

The concept of 'countervailing power' has been controversial ever since it was coined by Galbraith (1952). The theoretical literature has proposed several models of bargaining in vertical structures which relate buyer size to market power, but it did not develop a canonical setting for the analysis of two sided market power.[26] By modeling the inter-dependencies among the players as a cooperative game we avoid assumptions on details of the negotiation process altogether. We assume that players can make efficient use of the network and by using the Shapley value we derive the power structure endogenously from the agents' role in gas production, transport and consumption. In this way we separate the issue of power from the issue of efficiency. The institutional changes have no effect on the efficiency of the industry, they affect only the power structure.

The cooperative approach separates the paper from most of the applied studies on the European gas market, e.g. Grais and Zheng (1996), Boots et al. (2004), Von Hirschhausen et al. (2005), Egging and Gabriel (2006), and Holz et al. (2008). Notwithstanding a number of differences they all analyze the gas industry as a

[26]See among others Horn and Wolinsky (1988), Von Ungern-Sternberg (1996), Snyder (1998), Chae and Heidhues (2004), Inderst and Wey (2003).

succession of activities (production, transport, distribution), where the interaction among players of the same level of activity is modeled as a non-cooperative game either in linear prices or quantities. In addition, it is often assumed that the different levels decide in a given order, which essentially implies that those who move first (producers) have the ability to commit, whereas those who move later (transiters, importers) cannot commit (Grais and Zheng (1996), Boots et al. (2004)). While this approach has computational advantages when solving large disaggregated models, we do see two important conceptual shortcomings. First, the distribution of power between producers, importers and customers is largely determined by ad hoc assumptions on the type of interaction at the different levels and on the sequencing of actions, hence, the ability to commit. Second, the literature ignores that most pipeline gas is delivered under negotiated, comprehensive price-quantity-contracts. These contracts with so called 'take–or–pay' provisions stipulate prices *and* quantities to ensure the efficient usage of the capacities (see Energy Charter Secretariat (2007) for details). Contracts with transit countries also cover tariffs *and* quantities. Instead, the literature adopts counter-factual assumptions from the standard Cournot or Bertrand set up. In combination with market power, these restrictions on the strategy space lead to inefficiencies (double marginalization), which can be avoided by the contracts, which exist in the real world.

The paper is closely related to Hubert and Ikonnikova (2011b). Their focus however is on the impact of pipelines and their regional scope is too narrow to allow for an analysis of changes in market structure. Here we extend their model to include several competing producers and transit countries such as Turkey. We also allow importers in the European Union to act strategically. With these modifications we can assess the reform's impact on all major market participants. Finally, the paper shares the quantitative model of the gas industry and the calibration with Hubert and Cobanli (2014) who analyze the impact of strategic pipeline investments on the power structure.

1.2 The Approach

In this section we briefly describe the representation of the physical network, the cooperative game, the solution concepts and the model calibration. More details are given in the technical appendix at `http://www.ms-hns.de/research_gas` and at `http://www.ms-hns.de/paper_gas_countervailing`. While addressing a different topic, this paper uses the same approach as Hubert and Orlova (2014b), Hubert and Cobanli (2014), and Cobanli (2014). Hence, there is considerable overlap with the corresponding sections in these papers, and the reader may skip it if familiar with any of the other papers.

1.2.1 The Model

The Eurasian gas network consists of a set of nodes R, which may be production sites R_P , customers R_C or transit-connections R_T, and a set of directed links L representing pipelines. A link $l = \{i, j\},\ i \neq j \in R$ connects two nodes. Gas flows are denoted f_{ij} where negative values indicate a flow from j to i. For those links, which connect a producer to the network or the network to a customer, flows have to be positive ($f_{ij} \geq 0,\ \forall\, i \in R_P$ or $j \in R_C$). For each link $\{i, j\}$ we have a capacity limit k_{ij} and link specific transportation cost $T_{ij}(x)$, which includes production cost in case of $i \in R_P$. For capacities which already exist, transportation costs consist only of operation costs, because investment costs are sunk. When we allow for investments to increase k_{ij}, the capital costs for new capacities are added to the transportation costs. Each customer is connected through a single dedicated link to the network. So consumption at node $j \in R_C$ is equal to f_{ij} and the inverse demand is $p_j(f_{ij})$.

The set of strategic players is denoted N. The interdependencies among the players can be represented by a game in value function form (N, v), where the value (or characteristic) function $v : 2^{|N|} \to R_+$ gives the maximal payoff, which a subset of players $S \subseteq N$ can achieve. The legal and regulatory framework determines the access rights of the various players. So for any coalition $S \subseteq N$ we have to determine to which pipelines $L(S) \subseteq L$ the coalition S has access. Access to the link $\{i, j\},\ i \in R_P$ is equivalent of having access to production at p. Access to $\{i, j\},\ j \in R_C$ yields access to customer j. The value function is obtained by maximizing the joint surplus of the players in S using the gas-flows in the pipelines:

$$v(S) = \max_{\{f_{ij} | \{i,j\} \in L(S)\}} \left\{ \sum_{\{i,j\} \in L(S),\ j \in R_C} \int_0^{f_{ij}} p_j(z)dz - \sum_{\{i,j\} \in L(S)} T_{ij}(f_{ij}) \right\} \tag{1.1}$$

subject to the node-balancing constraints $\sum_i f_{it} = \sum_j f_{tj},\ \forall\, t \in R_T(S)$, the capacity constraints of the network $|f_{ij}| \leq k_{ij},\ \forall \{i, j\} \in L(S)$ and non-negativity constraints $f_{ij} \geq 0,\ \forall\, i \in R_P$ or $j \in R_C$. The value function captures the essential economic features, such as the geography of the network, different cost of alternative pipelines, demand for gas in the different regions, production cost, etc. It also reflects institutional features, such as ownership titles and access rights.

Finally, we calculate the Shapley value, ϕ_i, $i \in N$, which is player i's weighted contribution to possible coalitions:

$$\phi_i(v) = \sum_{S:i \notin S} P(S)\,[v(S \cup i) - v(S)] \tag{1.2}$$

where $P(S) = |S|!\,(|N| - |S| - 1)!/|N|!$ is the weight of coalition S. The Shapley value assigns a share of the surplus from cooperation to each player, which will be also referred to as his 'power'. Usually we express the power in relative terms as a share of the total surplus.

Suppose we start with an institutional setting generating the value function v^o. By changing access rights we obtain a new game characterized by v^1. The impact of the change on a player i is then given by $\phi_i(v^1) - \phi_i(v^o)$.

When deriving the value function, we have to make two major assumptions on the scope of the game. The first refers to the temporal scope and the second refers to the geographical scope including the level of regional disaggregation.

1.2.2 Specification & Calibration

Temporal scope / network flexibility.

We assume a stationary environment with constant demand, technology and production cost etc. The value of a coalition, nevertheless, depends on the temporal scope of the model (Hubert and Ikonnikova (2011b)). In the short run, there are less instruments available to increase the surplus than in the long run. It is instructive to look at three different scenarios:

Very short term: It covers a time span lasting up to several weeks. The Ukrainian transit crisis in January 2009 may be taken as practical illustration for this case. The events showed the immediate impact of the withdrawal of one player, Ukraine, on gas flows and consumption, given the very high demand in the winter season, peaking load on major transport links and maximal withdrawal from storage facilities. The 'very short term' is like an emergency scenario, in which only gas flows can be redirected.

Short term: Here we consider a span of one year up to perhaps three years. Such a period allows to ignore the seasonal pattern of demand and the possibility of gas storage.[27] It is also long enough to convert existing pipeline to bidirectional

[27] In Europe storage facilities help to smooth seasonal patterns of consumption, but at present they

usage but too short to build new pipelines or develop new fields. We refer to this variant as the 'status-quo' variant, because pipeline capacities are static. It can also be interpreted as a 'shortsighted' assessment of power, because the effects of adjustments which take longer than two or three years to be achieved are simply ignored.

Long term: Here we envisage a scenario in which transport capacities can be increased. As a result the network is considered to be flexible. As these investments will take at least a couple of years to become effective, we consider a period starting some three years ahead from the date for which we assess the power structure. We refer to this variant as flexible network, because a coalition can use (almost) all investment possibilities to enhance its value. It can be also considered as a 'farsighted' assessment of power because it ignores the period which is needed to bring new capacities on stream.

We assume that decision makers, when assessing bargaining power, look beyond the very short term emergency, but we are somewhat agnostic as to whether they tend more to the 'shortsighted' or to the 'farsighted' view. It is worth remembering that many gas contracts are long-term covering periods from 5 to 20 years, so we would expect that the conditions agreed on, reflect long term considerations. On the other hand, the further one projects into the future, the more uncertain the prospects become, so that the clearer short term options may exert a stronger influence on relative power. In any case, we will report results for both cases and take these as limits for the range in which we would expect the true values to be.[28]

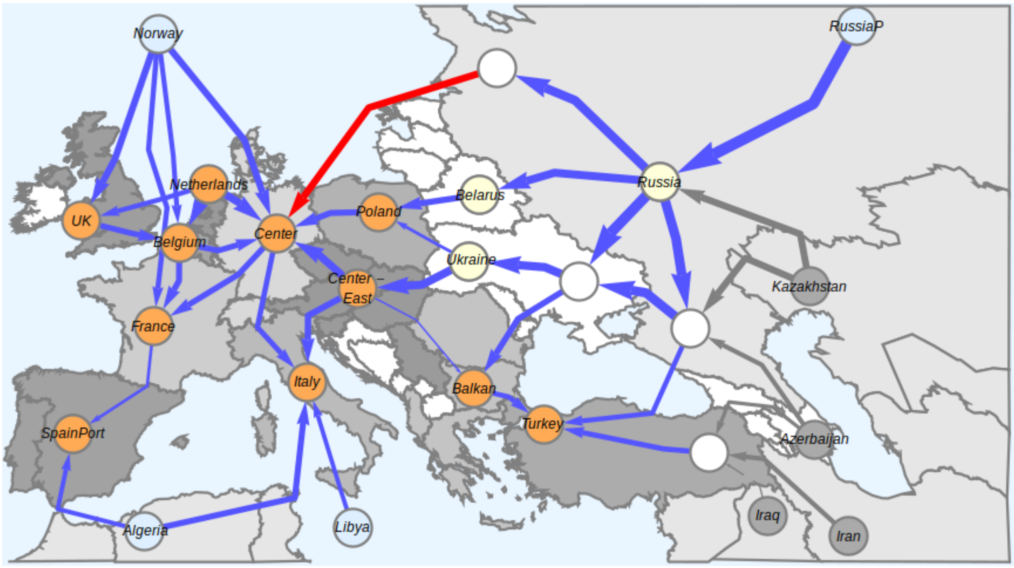
Geographical scope.

To obtain a detailed representation of the various customers, owners of pipelines and gas producers etc. we would like to consider a large set of players. Unfortunately, computational complexity increases fast in the number of players, as we have to solve $2^{|N|} - 1$ optimization problems to calculate the value function. It is for computational reasons that we restrict the geographical scope by aggregating cus-

are too low to act as a strategic reserve for longer periods.

[28]As pointed out in Hubert and Ikonnikova (2011b), due to the linearity of the Shapley Value, the 'shortsighted' and the 'farsighted' assessment can be combined easily to obtain a more balanced result. Let v^s denote the value function and ϕ^s be the power index for the 'shortsighted' game and v^f and ϕ^f characterize the 'farsighted' variant, then the Shapley value of the weighted game is given as weighted average of the two Shapley values $\bar{\phi} = \delta\phi^s + (1 - \delta)\phi^f$.

Figure 1.1: The Network



Blue nodes represent producers, major transit nodes are white. Russia, Belarus and Ukraine are marked with yellow color as we introduce domestic consumption for these countries. Orange points represent regions where we have a major transit node, which is linked to local production and local customers (the nodes are not shown separately). Solid arrows represent the main pipelines as existing in 2005. Grey nodes and pipelines are taken into account but not considered as strategic instruments. The red pipeline is Nord Stream, which started the operation recently.

tomers into large markets and leaving out producers which appear to be of minor strategic relevance (for a stylized picture of the network see figure 1.1).

As to outside producers we focus on Russia, Norway, Algeria and Libya which together cover about 85% of the gas imports into the European Union.[29] Main transit countries for Russian gas are Belarus and Ukraine. We introduce domestic consumption for Russia, Belarus and Ukraine. Turkey is a major gas consumer and a possible transit country for Russian gas. We aggregate customers and producers within the European Union into ten regional players. Each controls local production, access to local customers, and possibly transit through the region. France, Italy, Poland, Netherlands, UK and Belgium correspond to the respective countries. In each of these countries a national champion dominates imports and local supply (GDF, ENI, PNGiG, Gasunie, Botas). We collect Austria, Czech Republic, Slovakia, Hungary, Serbia and Slovenia in one region called “Center-East”. South Stream and Nabucco would end in Center-East, from where gas would be distributed to other European consumers. The countries in the region exhibit similar consump-

[29] Figures are calculated for the year 2009 from BP (2010).

tion and import dependency patterns. With very little alternative supplies the region depends with 80 % of its imports on Russia. While the pipeline networks are largely privatized, some owned by Western importers, the Austrian OMV can be seen as the dominant private supplier in the region. Germany, Switzerland, Denmark and Luxembourg are bundled to “Center”. In terms of consumption the region is clearly dominated by Germany, which is also home of large Gas suppliers E.ON-Ruhrgas and Wintershall. The region covers more than three quarters of gas consumption by imports, but its pipeline imports are well diversified between Russia (35%), Norway (34%) and Netherlands (26%). Spain and Portugal are aggregated into “SpainPort”. Finally, we collect Romania, Bulgaria and Greece in a region called “Balkan”. The region has only weak links to other European regions and imports mainly Russian gas. We aggregate all pipelines and interconnection points between any two players into one link. As to access rights, we assume that outside EU every country has unrestricted control over its pipelines and gas fields.

Cost and demand.

The details of the numerical calibration are given in a technical appendix. Here we outline only the main principles. We assume piece-wise linear production cost for each producer and linear demand functions with the same intercept for all regions. The model is calibrated using data on consumption in the regions and flows between the regions from 2009. Production cost have a common base, to which we make minor regional adjustments to replicate flows in 2009. The slope parameters of demand are estimated as to replicate the consumption in 2009. The most important implication of our calibration of demand in relation to cost is that the pipeline system as existing in 2009 is sufficient. Given the willingness to pay and the cost of supplying gas the network is able to deliver the efficient amount of gas into the different consumption nodes. Nevertheless, the options to change the network will affect bargaining power, because they allow coalitions, which do not have access to the full network, to adjust it to their needs.

This approach also ensures that the main difference between the regions is the relation of total consumption to own production on which we have solid information and not our assumption on demand functions on which information is poor. The main difference between producers is production capacity and pipeline connections to the markets, for which data are good, and not differences in wellhead production cost, which are difficult to estimate.

1.3 Results

Since a player's Shapley Value is the weighted sum of his contributions to the values of possible coalitions of other players, any change can be traced back to changes of these contributions. The value of a coalition depends on its access to pipelines, markets and gas fields. Hence, a player can increase the coalition value by providing additional markets, additional supply or by improving connections through transit. In any case, the value of his contribution will depend on how well his resources complement what is already there. Adding a market to other markets with no access to production helps little compared to making the same market available to several producers, which are short of customers.

When we assess the impact of a change in the rules for pipelines access, we compare the power index for two games. Generally speaking, a player benefits from getting better access to complementary inputs himself, but at the same time suffers from competitors also gaining better access. More specifically, a producer may gain from better access to markets, but he may suffer from his rivals improved access to the same markets, i.e. increased supply competition. A customer may gain from better access to suppliers, but he may suffer from other customers improved access to the same producers, i.e. increased demand competition. Finally, a transit country may gain from better access to markets and suppliers, but it may be harmed by other transit routes gaining access to the same markets and suppliers, i.e. increased transit competition. The change of own access will feature prominently in those coalitions, which do not include major rivals, whereas the effect on competition will be stronger in coalitions which include many potential rivals.

The trade-off between access and competition is complicated by the fact that some countries play multiple roles. For example, Center-East is a major gas customer, a transit region for Russian gas flowing westwards, and a transit region for North-Western gas flowing eastwards. Moreover, the role of a player depends on the coalition against which he is evaluated. For example, Italy and Turkey are importers when all players are in the coalition. However, Turkey becomes a transit country for Russian gas in a smaller coalition, for which neither gas from North Sea nor transit through Belarus and Ukraine is available. Similarly, Italy becomes a transit country for North-African gas, if other producers drop out. If we consider coalitions consisting only of countries, which are customers in the grand coalition, those with higher own production relative to demand should start exporting. Multiple and changing roles make it sometimes difficult to predict, what the overall impact of a measure on a player will be.

1.3.1 Fragmented Market

Our benchmark structure reflects the situation in Europe before the onset of reforms. We consider a fragmented market composed of regional monopolies, each controlling local production and both the high pressure transport network, hence, long distance gas transit, as well as the low pressure distribution network, hence, access to the customers in its region. While each customer can access producers only through the 'regional champion', we can accommodate various institutional arrangements at the local level. The champion may be a private profit maximizing firm efficiently exploiting local customers or an efficient public utility acting in the best interest of its constituency. In other words, we focus on how the surplus is shared between regions but we are agnostic about rent sharing within a region.

For this institutional set up we consider two network scenarios. The first reflects major pipeline as operational around the year 2005. The second takes into account the new offshore pipeline Nord Stream. For each network scenario we look at the shortsighted and the farsighted assessment of bargaining power, leaving us with four variants of the benchmark structure. In table 1.1 we report the Shapley values for the different variants. To simplify the interpretation, we consider only the surplus from cooperation regarding pipeline gas. So we deduct the payoff, which players can obtain on their own (e.g. from consuming own production or LNG import). All figures are given as percent of the total surplus. Figures in the first column report the shortsighted power assessment for the old pipeline network. Altogether, the group of outside producers, transit countries for Russian gas and the major EU supplier, the Netherlands, obtains a share of 46 per cent. The Russian supply chain receives more than half of this share or roughly a quarter of the total surplus. Belarus and Ukraine gain not only from transit, but also from consuming Russian gas. Other powerful producers are Algeria, Norway and Netherlands with shares of 4.7, 9.7 and 5.0, respectively. Their shares reflect their production capabilities but also their strategic location vis-a-vis major customers. Turkey and the EU countries (except Netherlands) benefit mainly through imports and transit of gas. Typically, their shares increase in the size of their own market, decrease in the amount of gas obtained through alternative means such as own production and LNG imports, and increase in their importance as a transit region. With a share of 17.9 Center, which includes Germany, Switzerland and Denmark, benefits most from cooperation. It

Table 1.1: Fragmented Market: Exclusive Access to Trunk Pipes

	Shapley Values in percentage of the total surplus			
	without Nord Stream		with Nord Stream	
	shortsighted	farsighted	shortsighted	farsighted
Russia	13.2	16.4	16.0	16.9
Belarus	4.5	4.0	4.1	3.9
Ukraine	7.7	5.8	6.2	5.4
Algeria	4.7	4.0	4.4	3.9
Libya	1.5	1.2	1.4	1.2
Norway	9.7	7.4	7.7	7.0
Turkey	1.8	1.7	1.8	1.7
Netherlands	5.0	3.9	4.1	3.8
Balkan[a]	0.7	1.1	0.6	1.1
Belgium	3.9	3.8	3.9	3.8
Center-East[b]	7.0	6.7	6.7	6.6
France	5.3	5.8	5.6	5.9
Center[c]	17.9	20.5	20.7	21.0
Italy	12.3	13.2	12.7	13.2
Poland	1.9	1.7	1.6	1.6
Spain/Portugal	0.9	1.1	0.9	1.1
UK	1.9	1.8	1.8	1.8
sum EU	56.9	59.5	58.5	59.9

[a] Romania, Bulgaria and Greece

[b] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[c] Germany, Switzerland, Denmark and Luxembourg

is a large market with little own supply or LNG imports and a strategic location for potential gas transits. Balkan (0.7), in contrast, collects a number of countries with little consumption, considerable own production and few transit options.

In the farsighted assessment (second column), we employ a longer perspective and allow for investment in additional pipeline capacity. It is worth remembering that due to our calibration the grand coalition of all players would decide against such investments. Nevertheless, the investment options have a substantial impact on the power index. Russia increases its share by 24 percent up to 16.4, while the transit countries Ukraine and Belarus see their shares cut by 25 and 11 percent, respectively. Russia's main competitors Algeria, Norway and Netherlands all loose about a fifth of their shares. Center and Italy gain while Center-East looses bargaining power. To a large extent these effects are driven by the option to invest in Nord Stream.[30] There are two exceptions, Balkan and Italy, which mainly gain from

[30] A similar result has been obtained in Hubert and Ikonnikova (2011b) for the North-Western region

the option to strengthen pipeline links to the Center-East and Center. The figures in columns 3 and 4 assess power for the time after the completion of Nord Stream. Comparing columns 3 and 1, we see that the completion of Nord Stream with a capacity of 55 bcm/a has a strong impact on the shortsighted power index. In fact the shortsighted power index when having Nord Stream in place, hence investment cost sunk, is similar to the farsighted index (column 2) when Nord Stream is only an expensive option (again Balkan and Italy are the exception). Accounting for additional investment options in other links has only little effect on the power index. After the completion of Nord Stream, the differences between a shortsighted and a farsighted evaluation (column 3 and 4) become small.

1.3.2 Integrated Market

Starting from a fragmented market, an integrated market is achieved by liberalizing access to the high pressure pipelines within EU. While regional champions still control local production and access to low pressure distribution, hence local customers, they cannot block long distance transit. As a result, competition between the regions as well as among producers is enhanced. A priory, the effect is ambiguous. On the one hand producers gain through improved access to customers. For example, in a fragmented market, Russia needs the cooperation of Center and Poland or Center-East to deliver gas along the eastern corridor to reach customers in France. With liberalized access, Russia is entitled to use the transit pipelines and needs only the distribution network in France to access the customers in this region. Russia as a producer and France as a customer gain by saving transit rents at the cost of Center, Center-East and Poland. By the same argument, however, competition between producers is intensified. In a fragmented market, producers enjoy market power vis-a-vis captured customers, i.e. those regions which need cooperation of other European countries to access alternative suppliers. After liberalization of pipeline access, any two producers connected to the European transit grid will compete for any European customer.

In table 1.2 we present the impact of integration measured as the change in percentage point compared to the benchmark cases in table 1.1. Perhaps the most important result is that the members of the Union as a group lose from liberalizing gas traffic among themselves. Their share decreases by 1.7 percentage points of the surplus in a shortsighted assessment of power before Nord Stream is available

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of the network.

Table 1.2: Impact of Wholesale Market Integration

	Change in percentage points compared to table 1.1			
	without Nord Stream		with Nord Stream	
	shortsighted	farsighted	shortsighted	farsighted
Russia	−2.7	−3.7	−2.9	−3.7
Belarus	1.5	1.3	1.2	1.3
Ukraine	0.3	0.1	−0.1	0.0
Algeria	0.4	0.7	0.0	0.6
Libya	0.2	0.2	0.1	0.2
Norway	1.8	2.1	2.0	2.1
Turkey	0.2	0.4	0.2	0.4
Netherlands	0.2	0.4	0.4	0.4
Balkan[a]	0.0	−0.3	0.0	−0.2
Belgium	−1.0	−0.7	−0.8	−0.7
Center-East[b]	1.0	2.0	1.9	2.2
France	0.7	0.7	0.9	0.8
Center[c]	−3.0	−4.3	−4.7	−4.6
Italy	1.1	1.4	1.7	1.5
Poland	−0.4	0.0	0.0	0.1
Spain/Portugal	0.0	−0.1	0.0	−0.1
UK	−0.2	−0.3	−0.1	−0.2
sum EU	−1.7	−1.2	−0.6	−0.9

[a] Romania, Bulgaria and Greece

[b] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[c] Germany, Switzerland, Denmark and Luxembourg

(column 1 of table 1.2). The losses become smaller in a farsighted evaluation of power (-1.2) or when Nord Stream is online (-0.6 and -0.9 for short and farsighted variant, respectively). These results cast into doubt that it is in the general interest of EU to liberalize access to the transmission networks. In other words, the results support the view that strong regional monopolies may be needed to counter the power of large producers. However, there are marked differences in the way the redistribution of bargaining power affects the various regions within EU as well as the various producers outside.

EU Countries.

Center, here a union of Germany, Denmark and Switzerland, depends little on transit within EU. The region is directly connected to Netherlands and Norway and has already two competing supply routes, Ukraine/Center-East and Belarus/Poland, for Russian gas, to which the completion of Nord Stream added a direct link. Hence, as a customer Center has little to gain from liberalization. At first glance Center's role as a transit country may appear to be modest. With 4.3 bcm/a and 9.1 bcm/a gas flows through Center to France and to Italy, respectively, are not particular large. However, the region is Europe's most important *potential* gas hub. Whenever one of the major producers is taken out of the picture, Center becomes a central transit region. Suppose Russian gas flows through Ukraine are interrupted. Norwegian and Dutch gas would have to flow through Center to reach Center-East and Italy. Similarly, if Norway's gas is to be substituted by supplies from Russia and Netherlands, these would have to travel through Center to reach the customers. Due to its strategic location Center enjoys substantial bargaining power as a potential transit region, which is lost when pipeline access is liberalized. As a result Center carries a loss of 3.0 percentage points, which further increases in the farsighted assessment or with the completion of Nord Stream. Belgium is another EU member, which will loose from liberalization for similar reasons.

Center-East $(+1.0)$ and Italy $(+1.1)$ in contrast, are regions set to gain from liberalized pipeline access. They highly depend on pipeline gas, but being directly connected only to one producer have little leverage over suppliers. As a result their bargaining position is strengthened through improved access to alternative suppliers. Somewhat surprisingly, even for Center-East, the important transit country for Russian gas, improved supply competition matters more than the loss of transit power. Center-East features higher gas transits than Center, but at the same time is more easily substituted for, in particular after Nord Stream becomes available.[31]

The pattern differs for Poland. Though Poland, as Center-East region, is the captured customer of Russia, it suffers a small loss of power (-0.4). On the one hand, Poland has much smaller market than Center-East. On the other hand, Poland is an important transit region for the Western part of the network and for Belarus with minor own production. For Poland the loss of transit power matters more than the improved supply competition. However, after Nord Stream becomes available, Poland is more easily substituted for and the negative effect is offset.[32]

[31] The liberalization's impact on the Shapley values given in table 1.2 already nets out gains in the contribution to some coalitions and losses in the contribution to others. If we look at these two components separately, we find that Center's gain from increased supply competition $(+1.3)$ constitute roughly a half of those for Italy $(+2.8)$ and Center-East $(+2.7)$, which have much smaller markets. Loss from curbing transit power and increased demand competition, in contrast, is - 4.4 percentage points for Center, much larger than Center-East's (-1.7).

[32] Poland, having much smaller market than Center-East, gains only $+0.4$ percentage points from

Outside Producers and Transit Regions.

Russia faces important transit constraints outside EU, but with respect to EU itself it can deliver gas through a number of geographically diversified entry points such as Balkan, Center-East, Poland and Center (with Nord Stream). It also has direct access to Turkey. As a result, Russia gains little in terms of market access but will loose in terms of increased supply competition for regions such as Poland and Center-East. Norway starts from the opposite position. With its main connections all located in the North West, it has less diversified access to Europe. Moreover, it does not benefit from 'captured customers', as Russia does. Norway faces direct competition from Netherlands, which neighbors its direct customers. To reach other important markets, such as Italy, France and potentially Center-East and Poland, it depends on transit through Center and Belgium. As a result Norway gains from the integration through improved market access.

Liberalizing pipeline access within the EU increases the power of Belarus and has an ambiguous effect on Ukraine. On the one hand, both transit countries for Russian gas have domestic consumption and, hence, gain through improved access to alternative sources of gas. On the other hand, in the integrated market it becomes cheaper to circumvent each of the countries, but, as long as Nord Stream is not available, it requires the other country to do so. For example Russian gas can bypass Ukraine by flowing through Belarus, Poland, Center and back to Center-East and Italy. Avoiding transit rents for Poland and Center enhances the position of Belarus and weakens the position of Ukraine. As a result, when Nord Stream is not taken into account, Belarus and Ukraine gain 1.5 and 0.3 percentage points, respectively. With Nord Stream the positive effect of the improved access to markets is weakened for both countries, so that benefits of Belarus decrease $(+1.2)$, while Ukraine is exposed to the slight loss of power (-0.1).

1.3.3 Integration and the Risk of Producer Cartels

Several initiatives of gas producing countries to establish a cartel similar to the OPEC have failed to produce tangible results. At first glance this may look surprising as it requires only a small number of major exporters to Europe to coordinate. One reason may be that competition between producers is weak in a fragmented market and so may be the incentives to form a cartel to reduce competition. If com-

the improved supply competition. At the same time Poland suffers (-0.8) from a loss of transit power and increased demand competition.

Table 1.3: Pipeline Access and Producer Cartel

	Fragmented Market[a] shortsighted	/ farsighted	Integrated Market shortsighted	/ farsighted
	No cartel [absolute shares]			
Russia	16.0	16.9	13.1	13.2
Algeria	4.4	3.9	4.4	4.5
Norway	7.7	7.0	9.7	9.1
sum others	13.4	12.3	14.9	14.1
sum EU	58.5	59.9	57.9	59.0
	Impact of cartel: *Russia*, *Algeria* [differences]			
Russia+Algeria	1.5	1.7	0.7	0.6
Norway	0.1	0.2	1.0	1.3
sum others	−0.4	−0.3	−0.7	−0.5
sum EU	−1.2	−1.6	−0.9	−1.4
	Impact of cartel: *Russia*, *Algeria*, *Norway* [differences]			
Russia+Algeria+Norway	6.5	7.0	6.1	6.4
sum others	−1.1	−0.6	−2.2	−1.6
sum EU	−5.4	−6.5	−3.9	−4.8

[a]All variants are with Nord Stream being in place.

petition is increased through liberalized access to the transport system, the gains from cartelization may increase as well. However, our calculations show that liberalizing access to the EU transit system appears to decrease the risk of a producer cartel.

The upper panels of table 1.3 summarize previous results. The left panel gives figures for the case of exclusive access to pipelines obtained from the right panels of table 1.1. The right panel reports the shares for liberalized access. It can be obtained by adding the right panels of table 1.1 and 1.2. In the middle and lower panels we report the gains and losses from establishing cartels among gas producers. As expected cartels are profitable. If Russia and Algeria form a cartel against a fragmented market they gain 1.5 and 1.7 percentage points in the shortsighted and farsighted assessment of power, respectively. If all major exporters join the cartel, the gains increase to 6.5 and 7.0 points, respectively.

Cartels remain profitable in an integrated market, but the gains from cartelization become smaller. In a fragmented market, there are important instances of bilateral competition for customers, which create strong incentives for cartelization. For example Italy is a major customer for Russian and Algerian gas. In a fragmented market other potential suppliers, such as Netherlands and Norway, are kept at bay by the need to ensure transit. Hence Russia and Algeria gain a lot by eliminating their mutual competition. In an integrated market Italy's access to alternative sources of gas is improved. Hence, the rent for which Russia and Algeria compete is diminished and so are the gains from cartelization. At the same time the spill-over to competing producers becomes larger.

1.3.4 Mergers and Centralization

In the previous section we argued that liberalizing access to the long distance network hurts the regions within EU as a group. Forcing regional champions to open their trunk pipes to competitors, or even spinning them off into a separate business, works against the fragmentation of the market by loosening up the vertical integration of the industry. Now we will turn to the question, how horizontal concentration affects the power structure. Such concentration can be result of private mergers of 'regional champions' like the E.ON - Ruhrgas merger mentioned in the introduction. It can also be achieved through public intervention such as the attempts of the European Commission to coordinate the EU's foreign gas relations.

Following Segal (2003) we model a merger as a change by which one party, the 'proxy player', acquires the exclusive right to use the resources of the other parties, which thereby become 'dummy players'. This change of access rights defines a new game. For the merging parties, the impact is measured by the difference between the share of the proxy player and the sum of the individual pre-merger shares. For all other players it is simply the difference between their shares in the two games. We have to distinguish two cases depending on whether we start in a fragmented market with exclusive access to trunk pipelines or in an integrated market where access is liberalized. In a fragmented market, the parties merge local production, access to local customers, and their transport network. Once the market is integrated, the merger embraces only local production and customer access. A centralized external policy of the European Union can be analyzed in the same manner. All members transfer their decision rights as far as relations with outsiders are concerned to a central player. With respect to the outside world, political centralization yields the same result as if the national champions would merge into a single 'European super champion'.

Recall that a merger does not change the total surplus, which depends only on the cost of producing and transporting gas and the benefits from consuming it. Hence, it benefits the merging parties only if surplus is redistributed at the cost of non-merging players (outsiders). Under which circumstances can this be expected? As is shown in Segal (2003) the answer to this question turns out be complicated. It does not depend on whether the resources of the merging parties are complements or substitutes as such. Instead, a merger between two players i and j harms an outside player k, hence benefits i and j, if their complementarity is decreased (their substitutability is increased) by k.[33]

Table 1.4 presents the impact of selected mergers and centralization on the power structure. For simplicity we report only the shortsighted scenario with Nord Stream being operational. Left and right panels refer to the fragmented market and the integrated market, respectively. The figures indicate by how many percentage points the players' share will change in comparison to the relevant benchmark case. In the first column of the left panel we report the impact of a merger between Center and Center-East, two important transit regions in a fragmented market. Such a merger would make it easier for Russian gas to bypass Ukraine but also for Norwegian gas to reach Russia's captured customers. As a result, Ukraine looses 0.8 points, Norway gains 0.4 points, while the impact on Russia is negligible. Within EU, Netherlands gains for similar reasons as Norway but Italy suffers. Center and Center-East provide alternative import routes for Italy so they gain by avoiding transit competition. The merging parties gain 0.4 points and the EU in total would gain, because the bargaining power of outsiders is weakened. In an integrated market, however, the same merger has very different effects (left column in the right panel). It is no longer profitable for the merging parties (-0.3), nor it is for the EU (-0.3). Russia and transit countries gain, while Algeria suffers a small loss.

For a merger between Center and Italy we observe a similar pattern. In a fragmented market the EU gains at the cost of outsiders, although in this case the African producers Libya and Algeria loose while Russia and Norway gain. Inside EU the merging parties and Netherlands gain while Center-East suffers. Italy depends more on Center-East for importing Russian gas than Center, which has alternative routes (e.g. Nord Stream). So the merger diminishes the transit power of Center-East. In an integrated market, the merger becomes unprofitable for the

[33] Two players i and j are complements (substitutes) with respect to a group S of players, if i's contribution to value of S is larger (smaller) if S includes player j. k decreases the complementarity (increases the substitutability) of i and j, if this difference becomes smaller (or larger in absolute terms if it is negative), if S also includes k. In a complex network like ours, such a criterion will never be fulfilled for all possible S and all possible outsiders k, but the network structure determines what will be more prominent on average.

Table 1.4: Impact of Mergers and Centralized Bargaining

	fragmented Market[a]				integrated market[b]			
	Center is merged with							
	Center East	Italy	Nether-lands	all EU	Center-East	Italy	Nether-lands	all EU
Russia	0.0	0.4	−1.9	−1.3	0.2	0.3	−0.6	−0.5
Belarus	0.0	0.0	0.0	0.3	0.1	0.1	−0.1	0.1
Ukraine	−0.8	−0.1	−0.2	−0.9	0.2	0.3	−0.3	0.5
Algeria	0.0	−0.6	−0.2	−1.4	−0.1	−0.1	−0.1	−0.9
Libya	0.0	−0.2	−0.1	−0.5	0.0	0.0	0.0	−0.3
Norway	0.4	0.4	−0.6	−0.3	0.0	−0.1	−0.5	−1.7
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	0.4	0.3	-	-	−0.1	−0.1	-	-
Balkan[c]	0.0	0.0	0.0	-	0.0	0.0	0.0	-
Belgium	0.1	0.0	−0.8	-	0.0	0.0	0.0	-
Center-East[d]	-	−0.4	0.4	-	-	0.0	−0.1	-
France	0.0	−0.1	−0.1	-	0.0	0.0	−0.1	-
Center[e]	0.4	0.3	3.2	4.2	−0.3	−0.5	2.1	2.7
Italy	−0.4	-	0.3	-	0.0	-	−0.1	-
Poland	−0.1	0.0	0.1	-	0.0	0.0	0.0	-
Spain/Portugal	0.0	0.0	0.0	-	0.0	0.0	0.0	-
UK	0.1	0.0	0.0	-	0.0	0.0	−0.1	-
sum EU	0.4	0.2	3.0	4.2	−0.3	−0.4	1.7	2.7

[a]Shortsighted assessment with Nord Stream being operational. Difference to table 1.1, column 3.

[b]Shortsighted assessment with Nord Stream being operational. Difference to the sum of column 3 of table 1.1 and column 3 of 1.2.

[c] Romania, Bulgaria and Greece

[d] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[e] Germany, Switzerland, Denmark and Luxembourg

parties (-0.5) and the EU (-0.4), while Russia and transit regions gain in a similar fashion as if Center and Center-East would merge.

The third example of a pairwise merger is between Center and Netherlands. It would pool a major producer with a large market and important transit region. In a fragmented market this merger would be highly profitable both for the merging players (+3.2) as well as for EU as a group (+3.0). Within EU the power of Center-East and Italy increases by 0.4 and 0.3 percentage points, respectively. Both regions increase complementarity of merging Center region and Netherlands. In the fragmented market Center is a transit region for Italy and Center-East for gas from the Northwest, including Netherlands. Therefore, both customers increase complementarity of Center as transit region and Netherlands as a producer. Belgium in contrast is hurt (-0.8) because it competes with Center for Dutch gas. All outside producers are hurt by the merger, with Russia and Norway bearing the brunt of the losses. As in the other cases, liberalization of pipeline access tends to decrease the profits of a merger, but the effect is not strong enough to turn it into a loss. In an integrated market, the merging parties gain 2.1 points. The gain for EU (loss to outside suppliers) is 1.7 points.

If thought to an end, a sequence of pairwise mergers would lead to full centralization, which is also the aim of the EU's attempts to speak 'with a common voice' in all external energy relations. The last columns of the two panels show the impact of such a scenario. Bargaining as a group the EU would gain 4.2 percentage points in a fragmented market and 2.7 points when internal markets are already integrated.

In summary, we find that in a fragmented market pairwise mergers of 'national champions' tend to be profitable for the parties. There is however much heterogeneity in the impact on others. As a rule some outside producers gain while others loose and the same holds true for other regions in the Union. So we see little evidence for the view, that it takes large European players to counter the power of outside producers. Once market integration is achieved, the attractiveness of mergers is much decreased and the results become more homogeneous. Bilateral mergers within EU have small effects on their fellow EU regions, Norway and Algeria, but they tend to increase the power of the Russian supply chain.

The reason for this pattern is to be found in the architecture of the network. Overall, the transport system is designed to ship gas from different points at the periphery Northwest (Netherlands and Norway), East (Russia) and South (Algeria, Libya) to the various centers of consumption in Europe. In a fragmented market each European region enjoys exclusive control of sections of the network of trunk pipelines. As these pipeline sections tend to be complementary, customers depend on each other to access suppliers. Since outside producers are located at different points, it depends on the particular merger, whether an outside producer increases or decreases the complementary. Take Center and Italy as an example. With respect to Norwegian or Dutch gas Center and Italy are complementary. Italy depends on transit through Center. Algeria reduces this complementarity by providing an independent source of gas for Italy, so it is hurt by the merger. If we consider Russia instead of Algeria, supply in the North becomes very large, hence, Italy's market becomes more valuable for Center. So Russia increases the complementarity and, therefore, benefits from the merger. The first pattern is slightly more prevalent and tends to dominate other effects. As a result bilateral mergers of customer/transit regions tend to harm the group of outside producers and transit countries. However, the opposite case is also common and often the merging parties gain more at the cost of other regions within the EU.

In an integrated market each region enjoys access to the whole network. A merger joins access to customers and local production. The European regions are similar in the sense that they depend on imports, so they are competitors i.e. substitutable with respect to an outside producer.[34] In the previous example, with open access to trunk pipes Center and Italy become substitutable with respect to Norwegian gas. Russia, as additional producer, will reduce the competition between consuming regions and, hence decrease substitutability. Therefore, a merger tends to strengthen the bargaining power of Russia and the transit countries for Russian gas.

1.4 Concluding Remarks

For a long time European gas markets used to be dominated by 'national champions', vertically integrated firms, controlling local production, trunk pipes, hence imports, and distribution networks, hence access to customers. The EU Commission is trying to overcome this fragmentation by liberalizing pipeline access, breaking up vertical structures and fostering competition between the regions. Critics argue, however, that strong European players are needed to create buyer power against a small number of external gas suppliers, such as Russia, Norway and Algeria, on which the EU depends for more than half of its consumption.

[34] The main exception is Netherlands, which produces gas in excess of its own consumption.

In this paper we model the European gas supply system as a cooperative game and use the Shapley value as a power index for the players. We analyze how the liberalization of access to the European high pressure transport system affects the power of the various regions. Such a measure would establish an integrated wholesale market by stripping the national champions of their power to block interregional gas transit. However, it falls short of creating a truly competitive internal market, because access to local customer through low pressure distribution networks is still monopolized.

We find that forcing the European companies to open access to their network of trunk pipes, on balance, strengthens the power of external suppliers and transit countries for Russian gas and weakens the regions within EU. There is, however, considerable variety on both sides of the market, which might explain the difficulties of implementing the reforms in the European context. Though market integration tends to strengthen outside producers, it reduces their possible gains from establishing a producer cartel. Overall, with respect to long distance gas transport, we find some support for the claim that it takes ‘countervailing power’ to curb the dominance of outside producers.

In a fragmented market, pairwise mergers of local champions tend to be profitable and increase bargaining power vis-a-vis outside producers in many cases. But there are also many instances where outside producers gain power. So depending on the particular case, the argument of countervailing power has some validity. However, once access to trunk pipes is liberalized, many pairwise mergers turn unprofitable for the merging parties, mostly because they increase the bargaining power of the Russian supply chain. We also analyze the effect of a centralization of EU gas policy. Independently of whether we start from a fragmented or an integrated market, the EU can benefit a lot by “speaking with one voice”.

The next step towards a fully liberalized market would be to open access to customers, for example by unbundling local production from ownership of distribution networks. The national producer would loose its captured local customer base and have to compete against other producers inside and outside EU on level playing field. Most likely such a step will benefit customers within Europe, but again it might come at the expense of increased power of outside producers. In this sense the present paper provides only a partial answer to the question of whether it is worth to protect ‘national champions’ to curb the power of outside producers.

Appendix A

A.1 Calibration

In this section we describe the functions and parameters used for the calculation of the value function (equation (1.1) in the main text). Let f^*_{ij}, $\{i, j\} \in L(N)$ denote the solution to the program in (1.1) when solved for the grand coalition, which has access to all resources. To calibrate the model, we have to determine p_j and T_{ij} such that f^*_{ij} are reasonably close to observed consumption patterns and flows. As we assume that the players cooperate effectively, they will make efficient use of the existing network. Hence, in each region the marginal willingness to pay for gas, $p_j(f_{ij})$, will be equal to the local marginal cost of supplying gas, the nodal cost $c_j(f_{ij})$, which take into account the physical constraints of the system. We use this feature to calibrate first inverse demand and then supply cost using data on consumption and flows.

A.1.1 Demand

Transport costs within Europe are small compared to the cost of producing gas and transporting it to Europe's borders. As a first approximation, we neglect the small differences among local cost and assume a common constant supply cost c.[35] For each consumption region we assume a linear inverse demand function. To reduce the number of parameters we assume the same demand intercept $(a + c)$ for all regions. Efficiency requires $p_j(f_{ij}) = a + c - b_j f_{ij} = c$ for each region j. The slope parameters b_j are then calibrated as to replicate the consumption in 2009: $b_j = a/f_{ij}$, where f_{ij} is the consumption of gas in region j compiled from IEA (2010)

[35] For none of the links within Europe the capacity constraints were binding in 2009/10. So nodal cost differ only by the variable transportation cost between connected nodes which are small.

Table A.1: Pipeline Network: Consumption links

Links		Consumption [bcm/a]	Slope given $a = 500$	Players needed for access
from	to	f_{ij}	b_j	
Russia	RussiaC	426.4	1.2	Russia
Belarus	BelarusC	17.9	28.0	Belarus
Ukraine	UkraineC	53.3	9.4	Ukraine
Belgium	BelgiumC	16.9	29.6	Belgium
Poland	PolandC	16.0	31.3	Poland
UK	UKC	90.5	5.5	UK
Balkan[a]	BalkanC	20.2	24.8	Balkan
Turkey	TurkeyC	36.4	13.7	Turkey
Center[b]	CenterC	104.6	4.8	Center
Center-East[c]	Center-EastC	41.4	12.1	Center-East
Italy	ItalyC	75.6	6.6	Italy
Netherlands	NetherlandsC	48.3	10.4	Netherlands
France	FranceC	44.1	11.3	France
SpainPort[d]	SpainPortC	38.8	12.9	SpainPort

[a] Romania, Bulgaria and Greece

[b] Germany, Denmark, Switzerland and Luxembourg

[c] Austria, Hungary, Czech Republic, Slovakia, Serbia, Slovenia

[d] Spain, Portugal

and IEA (2011).[36] See Table A.1 for the resulting parameter values.

The common supply cost c acts as a shift parameter, which does not affect the consumer surplus. A decrease of a, with b_j being adjusted, affects all players proportionally. Such a change has little impact on the *relative* Shapley value (measured in per cent of the surplus), hence, will have little effect on our index for bargaining power.

A.1.2 Production

For each region we introduce a production link, which connects the production site and the network. We present the parameter values for the production links in Table A.2.

[36] All quantities are quoted in bcm/a. All prices or cost are quoted in mn €/bcm (giving the same figure as the more common €/tcm).

Our focus is on the imported pipeline gas, which is considered to be the marginal source of gas. For Russia, Belarus and Ukraine welfare includes the benefits from local consumption. We treat Norway, Algeria and Libya as pure producers which benefit only from export earnings. For these countries we consider only production which could be made available for exports to Europe and Turkey after deducting own consumption and exports to other markets. For all players, except Russia, we restrict the capacities of production links to be equal to the respective production volumes in 2009. The data on production volumes are collected from IEA (2010) and IEA (2011).

The differences in the operating cost of producing from existing fields are small compared to differences in the cost of developing new fields. In addition, meaningful information on wellhead production cost is difficult to obtain. As with demand we make a bold assumption by introducing a common production cost parameter c^P with some adjustments (Δ_{ij}) for few cases. Since it is more difficult to produce at maximal capacity k_{ij}, we assume production cost to be piecewise linear : $T_{ij}(f_{ij}) = (c^P + \Delta_{ij})(\min[f_{ij}, 0.75 * k_{ij}] + 1.2 \max[f_{ij} - 0.75 * k_{ij}, 0])$. Per unit production costs are constant, but only up to 75% of the pipe capacity and increased by 20% for the remaining 25%. These adjustments help to get more realistic flows for the network, but have only a negligible impact on our estimate of bargaining power. Since the demand system is adjusted to any choice of c^P, its absolute value is rather irrelevant and arbitrarily set as $c^P = 20$. To account for the regional differences in wellhead production cost we compute Δ_{ij} based on Table 13.6 (IEA (2009)). For most EU regions, as well as for Belarus and Ukraine, we ignore any cost of own production.

A.1.3 LNG

In case of all market structures a local champion (or a region itself) controls not only own production, but also LNG-imports. For all EU players we introduce LNG links, which represent the LNG terminals. The parameter values are reported in Table A.3. The data on LNG-imports are collected from GIE (2010), IEA (2010) and IEA (2011). In accordance with Table 13.5 and Table 13.6 in IEA (2009) we set the total costs of using LNG to be equal to $2c^P$ which gives LNG a slight disadvantage compared to pipeline gas. As before, we assume a piecewise linear cost function: $T_{ij}(f_{ij}) = 2c^P * (\min[f_{ij}, 0.75 * k_{ij}] + 1.2 * \max[f_{ij} - 0.75 * k_{ij}, 0])$, where k_{ij} denotes the capacity of the link. We restrict the capacities of LNG links to the respective flows in 2009.

Table A.2: Pipeline Network: Production links

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operating Cost $c^P + \Delta_{ij}$ [€/tcm]	Players needed for access
Production outside EU					
RussiaP	Russia	650.8	550.5	c^P	Russia
NorwayP	Norway	99.4	99.4	$c^P - 7$	Norway
AlgeriaP	Algeria	77.7	77.7	$c^P - 5$	Algeria
LibyaP	Libya	15.9	15.9	$c^P - 8.8$	Libya
BelarusP	Belarus	0.2	0.2	0	Belarus
UkraineP	Ukraine	21.9	21.9	0	Ukraine
Production within EU					
BalkanP	Balkan	10.8	10.8	0	Balkan
BelgiumP	Belgium	0	0	0	Belgium
CenterEastP	CenterEast	4.9	4.9	0	CenterEast
FranceP	France	0.9	0.9	0	France
CenterP	Center	23.7	23.7	0	Center
ItalyP	Italy	8.1	8.1	0	Italy
NetherlandsP	Netherlands	78.7	78.7	$c^P - 4.4$	Netherlands
PolandP	Poland	5.8	5.8	0	Poland
SpainPortP	SpainPort	0	0	0	SpainPort
TurkeyP	Turkey	0.7	0.7	0	Turkey
UKP	UK	62.1	62.1	0	UK

Table A.3: Pipeline Network: LNG links

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operating[a] Cost $c^P + \Delta_{ij}$ [€/tcm]	Players needed for access
BalkanLNG	Balkan	0.8	0.8	$2c^P$	Balkan
BelgiumLNG	Belgium	3	3	$2c^P$	Belgium
FranceLNG	France	10.1	10.1	$2c^P$	France
CenterLNG	Center	0	0	$2c^P$	Center
ItalyLNG	Italy	2.9	2.9	$2c^P$	Italy
NetherlandsLNG	Netherlands	0	0	$2c^P$	Netherlands
PolandLNG	Poland	0	0	$2c^P$	Poland
SpainPortLNG	SpainPort	28.5	28.5	$2c^P$	SpainPort
TurkeyLNG	Turkey	6.1	6.1	$2c^P$	Turkey
UKLNG	UK	10.1	10.1	$2c^P$	UK

[a] The global parameter c^P is set equal to 20. We give the unit cost for flows up to 75% of the capacity. For the remaining 25% of capacity the numbers are increased by 20%.

A.1.4 Transport

The total cost of transporting gas consists of operating cost and capacity cost. In the shortsighted assessment of power, capacity costs of existing pipelines are sunk and we do not take them into account. This simplification is based on the assumption that bargaining among rational players should not be influenced by sunk cost.

The operating cost is composed by management & maintenance cost and energy cost, which are proportional to the length of the pipeline as well as to the quantity of gas transported. Since it is difficult to run a pipeline throughout the year at maximal capacity, we assume a piecewise linear function: $T_{ij}(f_{ij}) = c^T_{ij} * (\min[f_{ij}, 0.75 * k_{ij}] + 1.2 * \max[f_{ij} - 0.75 * k_{ij}, 0])$, where k_{ij} denotes existing capacity. Per unit transportation costs are constant, but only up to 75% of the pipe capacity and increased by 20% for the remaining 25%. Capacities of the links between the transit nodes are compiled from ENTSOG (2010) and public sources. The data on flows are collected from IEA (2010) and IEA (2011). Capacities of the links, which are connected to the areas outside of the regional scope, are limited to the respective flows in 2009.

To calculate the link specific cost parameter c^T_{ij}, we assume universal operating cost of 0.3 €/tcm/100km for onshore pipelines. For offshore pipelines we assume operating cost to be 50% higher to account for higher pressure and increased cost of maintenance. These coefficients are then multiplied by the distance between the nodes to obtain the link specific operating cost shown in Table A.4 column 4.

A.1.5 Investment

In the farsighted scenario we allow for investment in new capacity for links within EU and in the pipelines for Russian gas. For additional capacities we add annualized capacity cost to the operating cost. To obtain capacity expenditures for new projects and enlargement of existing pipeline networks we refer to public sources for costs estimates of the project consortia, which are supplemented by own estimates if figures are unavailable. To simplify the analysis we abstract from economies of scale and assume constant capacity cost. We use a rather high discount rate of 15% to translate capital expenditures into annualized capacity cost. This rate is a common hurdle rate in the gas industry and reflects the real option nature of the investment and depreciation. For those links where investment is possible, transportation cost are given as: $T_{ij}(f_{ij}) = c^T_{ij} * (\min[f_{ij}, 0.75 * k_{ij}] + 1.2 * \max[f_{ij} - 0.75 * k_{ij}, 0]) + c^K_{ij} \max[f_{ij} - k_{ij}, 0]$, where c^K_{ij} denotes annualized capacity cost, measured

Table A.4: Pipeline Network: Transit

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operating Cost c^T_{ij} [€/tcm]	Capacity Cost[a] c^K_{ij} [€/tcm/a]	needed for access[b]
Transit outside EU						
Russia	Belarus	100	49.2	2.1	-	Russia, Belarus
Russia	RussiaN	165	0	2.3	-	Russia
Russia	RussiaS	240	8.9	2.1	-	Russia
Russia	UkraineE	415	109.1	2.0	-	Russia, Ukraine
RussiaS	UkraineE	200	24.6	1.2	-	Russia, Ukraine
UkraineE	Ukraine	122	95.1	2.5	12.6	Ukraine
TurkeyE	Turkey	20	11.8	2.4	12.1	Turkey
Transit into (out of) EU						
Algeria	Italy	30.2	25.4	6.2	-	Algeria*
Algeria	SpainPort	12	9.2	4.5	-	Algeria*
Libya	Italy	11	9	4.7	-	Libya*
Belarus	Poland	33	31.3	1.4	8.9	Belarus*
Norway	Belgium	15	12.2	5.2	-	Norway*
Norway	France	18.3	15.0	5.9	-	Norway*
Norway	Center	46	29.2	5.2	-	Norway*
Norway	UK	46.4	24.0	4.9	-	Norway*
UkraineE	Balkan	31.3	16.5	3.4	4.	Ukraine*
Ukraine	Center-East	105.8	77.0	1.9	9.5	Ukraine*
Ukraine	Poland	5	3.2	1.2	6.	Ukraine*
RussiaN	Center	0	0	6.9	26.8	Russia*
Balkan	Turkey	16.3	8.9	1.8	9.2	Turkey*
RussiaS	Balkan	0	0	5.6	23.8	Russia*
RussiaS	Turkey	16	8.9	4.8	11.9	Russia, Turkey
Transit within EU						
Belgium	France	30	14.9	0.8	4	In the integrated market access to transit pipelines within EU is free. *In the fragmented market both players from the left column are needed.
Belgium	Center	26	1.0	0.6	3	
Center-East	Balkan	1.7	1	3.3	16.5	
Center-East	Center	77.8	18.4	2.4	12	
Center-East	Italy	37.0	21.3	2.7	13.5	
Center	France	28	4.3	1.4	7.1	
Center	Italy	20.2	9.1	3.5	17.3	
Netherlands	Belgium	53	10.7	0.5	2.6	
Netherlands	Center	80	11.7	0.6	3	
Netherlands	UK	15.3	7.0	1.0	3.5	
Poland	Center	31.4	24.4	3.2	16.1	
UK	Belgium	25.5	7.5	1.5	4.9	
France	SpainPort	4.7	1.1	3.2	15.8	
Balkan	Italy	0	0	3.9	28.5	
Out of regional scope						
Azerbaijan	RussiaS	0	0	3.8	-	Russia
Azerbaijan	TurkeyE	4.5	4.5	2.4	-	Turkey
Iran	TurkeyE	7.2	7.2	1.2	-	Turkey
Iraq	TurkeyE	0	0	1.7	-	Turkey
Kazakhstan	Russia	0	0	5.1	-	Russia
Kazakhstan	RussiaS	32.3	32.3	3.6	-	Russia

[a] In the farsighted scenario we allow for investments in the links within EU and in the pipelines for Russian gas.

[b] We list the players which are needed in the integrated market. We mark with a * those cases, where there is a change for the fragmented market. Then both players from the left column are needed for access to a link.

in € per tcm per year (for figures see Table A.4 column 5).

Chapter 2

Network Access and Market Power

This chapter is based on a joint paper with Franz Hubert.

Abstract

We study the impact of the liberalization of EU natural gas markets on the balance of power between 'local champions', customers, and outside producers, such as Russian Gazprom. We distinguish between two steps of the reform: 1. opening access to transit pipes and 2. opening access to distribution systems, hence customers. Using the Shapley value as a power index, we find a modest and rather heterogeneous impact from the first step. The impact of the second step is much larger and yields a clear pattern: all local champions lose, while all customers and all outside producers gain. As one third of the losses of champions within EU leaks to players abroad, current reforms might enhance the dominance of already powerful outside producers. When network power is assessed with the nucleolus, in contrast, full liberalization of access to customers does not benefit outside producers at all.

Keywords: Network Access, Natural Gas, Countervailing Power, Shapley Value, Nucleolus
JEL class.: L1, L95

This paper is part of larger collaborative research project on the Eurasian gas network to which Onur Cobanli made essential contributions. We are thankful to Johannes H. Reijnierse for providing us with MATLAB code for calculating the nucleolus. We are also thankful for helpful comments from participants at the annual meeting of Verein für Socialpolitik, UECE Lisbon Conference and IMA Conference on Game Theory and its Applications.

2.1 Introduction

In the early nineties the European gas industry looked like a patchwork of regional monopolies. Typically, a state owned or tightly regulated domestic champion controlled (i) local gas production, (ii) the high pressure transmission grid, hence, gas transit, and (iii) the distribution networks, hence, access to local customers.[37] When taking up the challenge to develop this fragmented industry into an integrated and competitive common market, the European Commission identified the liberalization of access to gas pipelines as the key element for success. Transparent and fair access to the bottle neck facility creates a level playing field, which will allow competition to flourish. It is expected that consumers will benefit from a diversified choice of suppliers and competitive prices. But according to the Commission not only customers are supposed to gain from open pipeline access: "An integrated market also provides a more powerful bargaining position for European energy companies when sourcing energy in global markets since there is a larger range of options available as regards supply routes and better access to customers." [38]

Skeptics, however, point out that two thirds of the Union's gas consumption is imported from a small number of producers beyond EU jurisdiction. Russian Gazprom, Algerian Sonatrach and Norwegian Statoil, which alone account for more than three quarters of imports, have only negligible stakes in the intra-European pipeline network. They derive market power from controlling the source, gas fields outside the Union, not from owning pipelines within. In their opposition to the Commission's policy, national champions, and often their respective governments, claim that a limited number of strong European market players is needed to counter the power of these outside producers. It is argued that by dismantling the European champions, the Commission fosters the dominance of outside producers.[39]

The notion that it takes strong buyers to create 'countervailing power' against powerful sellers has been controversial among academic economists ever since it was coined by Galbraith (1952). The literature on deregulation and liberalization tends

[37]Obviously, this is an idealized description, fitting nicely to France/GdF, Austria/OMV, Italy/Eni. In Germany, however, there is E.ON-Ruhrgas, which faces a smaller rival Wintershall, and both have only limited stakes in the distribution networks. When gas pipelines were privatized in Slovakia and Czech Republic they were bought by foreign companies. Nevertheless, it is possible to identify a dominant player for most regions in Europe.

[38]Commission (2007a), p. 5.

[39]For a summary of the arguments see Commission (2007b)-Second Phase (public consultation).

to emphasize potential efficiency gains. In the gas industry, however, sunk investment in gas fields and pipelines creates large quasi rents, so that a loss of bargaining power can have a substantial impact on the distribution of welfare between customers, regional champions and outside producers.

The theoretical literature has proposed several models of bargaining in vertical structures, but it did not develop a canonical setting for the analysis of market power in vertical structures.[40] Previous studies on the impact of liberalization on the European gas market used a non-cooperative approach, e.g. Golombek et al. (1995), Boots et al. (2004), Egging and Gabriel (2006), and Holz et al. (2008). Notwithstanding a number of differences, this literature analyzes the gas industry as a succession of activities (production, transport, distribution), where the interaction among players of the same level of activity is modeled as a non-cooperative game either in linear prices or quantities. In addition, it is often assumed that the different levels decide in a given order, which essentially implies that those who move first, usually the producers, have the ability to commit, whereas those who move later, i.e. transit countries or importers, have to follow.

As already pointed out in Hubert and Ikonnikova (2011b) and Hubert and Orlova (2014a) there are several conceptional shortcomings of this modeling strategy. The distribution of market power depends on ad hoc assumptions on the type of interaction at the different levels of the value chain and the ability to commit which is determined by the sequencing of actions. Second, the literature assumes that the players are setting either quantities or (linear) prices, whereas in reality, most pipeline gas is delivered under negotiated, comprehensive price-quantity-contracts (so called 'take–or–pay' provisions). This counter-factual assumption implies double marginalization, an inefficiency, which is reduced if competition is enhanced through liberalization. It is worth emphasizing that the contracts which are widely used in the real world gas industry can exactly avoid this inefficiency. We suspect that the non-cooperative literature underestimates the ability of the actors to make efficient use of the existing pipeline system and, therefore, overestimates possible efficiency gains from liberalization.

In this paper we analyze the inter-dependencies among the players as a *cooperative game*. Thereby, we allow for comprehensive contracts and give none of the players an a-priory strategic advantage. Instead, the power of a player is derived

[40] See among others Horn and Wolinsky (1988), Von Ungern-Sternberg (1996), Snyder (1998), Chae and Heidhues (2004), Inderst and Wey (2003).

endogenously, entirely determined by his control over gas fields, pipelines and customers. In this way we also separate the issue of power from the issue of efficiency. In our framework liberalizing pipeline access has no effect on the efficiency of the industry, it will only affect the power structure. This allows us to focus on the alleged trade-off between enhancing customer's power on the one hand and keeping a lid on the power of external producers on the other.

There are several solutions for cooperative games. In this paper the emphasis is on the well known Shapley value. Following Shapley and Shubik (1954) the Shapley value has regularly been used as a power index for voting games, both in political science (Brams (2013)) as well as in corporate finance (Crama and Leruth (2013)). Myerson (1980) initiated a literature, where the Shapley Value is applied to communication structures and social networks, but so far only few attempts have been made to investigate the power structure in industrial networks. The main alternative to the Shapley value is the core, which is however, difficult to use as it does not yield a unique solution.[41] Following Montero (2005), we consider the nucleolus as an alternative power index. The nucleolus is of interest because it is in the core, provided the core is not empty, and can be considered as the lexicographical center of the game (Maschler et al. (1979)).

We are not concerned with the institutional details of liberalization, e.g. whether it is achieved by ownership unbundling or by regulated third party access. However, the distinction between access to high pressure trunk pipes, which are needed for *gas transit* across Europe and access to low pressure distribution networks, which allow for *access to customers* in a region, will be crucial. Conceptually, the Commission does not draw such a distinction, though in practice, the liberalization of transmission networks is advancing at a faster pace.[42]

To obtain a differentiated picture we start from a *fragmented market* in which regional champions control local production, transmission, and access to local customers. This scenario captures the stylized features before the onset of reforms. In a first step, we consider the liberalization of access to the transmission networks. With free transit, we obtain a regime which we call an *integrated market*. Local champions, as well as external producers, can ship their gas freely within the

[41] Later we will calibrate a model with 20 players. As a result the core is characterized by over a million inequalities.

[42] In the year 2003 the Directive 2003/55/EC (EU (2003)) specified deadlines for legal unbundling of July 2004 and July 2007 for transmission and distribution networks, respectively.

Union, but the champions remain the gatekeepers of access to local customers. This intermediate scenario roughly corresponds to the current status of the implementation of reforms. In a second step, we also allow for open access to distribution networks, a scenario to which we refer as *liberalized market*. Here, the champions are reduced to local producers, competing for customers against each other and against the outside producers. We take this scenario to reflect the final aim of the Commission's liberalization policy.

Opening access to trunk pipes is likely to have very different effects on the power structure than opening access to distribution pipes. Consider the example of Russian Gazprom planning to supply gas from the German/Polish border to a customer in France. In a fragmented market, it needs the cooperation of the French champion Gaz de France to access the customer, and the German champion E.ON-Ruhrgas to transport the gas to France. Both partners will use their leverage to extract some of the surplus of the deal between the external producer and the local customer. In an integrated market, access to transmission networks is open and Gazprom can do away with the German champion, but it still needs the cooperation of Gaz de France to access the customer. Cutting out the German 'middleman' will benefit Gazprom, Gaz de France, and the French customer. In this sense, Gaz de France and its customers may gain from improved access to other producers outside and inside the Union. However, the overall impact of market integration is more complex because Gaz de France, as other regional champions, also loses its transit power. A gas poor region with privileged location for Russian gas, such as Poland, will be exposed to tougher competition from customers in other regions as gas is more easily shipped away from its borders. On the other hand, it will also benefit from easier access to alternative suppliers.[43]

Now consider the case, when, in addition to transit pipelines, access to the distribution networks is liberalized. In such a fully liberalized market, Russian Gazprom and the French customer can cut out both, the German and the French champion. Regional champions lose the ability to extract rents from controlling transit and access to customers and are reduced to their function as local producers. Customers and outside producers will gain through improved access to suppliers and markets, respectively. But it is difficult to imagine how such a move could strengthen the bargaining position of European energy companies, as it is claimed by the Commission's statement cited above.

[43]These regional effects have been analyzed in detail in Hubert and Orlova (2014a).

Our quantitative results support this intuition if network power is assessed with the Shapley value. Overall, we find modest and heterogeneous effects for the opening of access to transit pipelines. Customers in the union tend to gain. The exception are customers in the Netherlands, which enjoyed a privileged position with respect to ample local supplies in a fragmented market. Local champions in the central regions providing transit for Russian and Norwegian gas lose bargaining power, while those which are located more at the receiving end, e.g. Italy and France/Spain, gain from improved suppliers access. All these effects, however, are fairly small and the aggregate impact on the balance of power between customers and champions within the European Union on one side, and outside producers and transit countries on the other side is negligible.

If we add the liberalization of access to distribution networks, thus moving on to a completely *liberalized market*, the effects are amplified by order of magnitude and a simple pattern emerges. Compared to the initial situation of a fragmented market, the power of customers is substantially enhanced in all regions of the European Union, while the power of the old champions, now reduced to local producers, is dramatically diminished. Roughly a quarter of the joint share of the European players is redistributed through the reform. However, more than a third of what is taken from the champions ends up not with European customers, but with external suppliers and transit countries. We do not find support for Galbraith's controversial hypothesis that customers would ultimately benefit from countervailing power. Quite to the contrary, European customers do gain a lot from dismantling the power of local champions, but there is also a very substantial 'leakage', benefiting outside producers.[44]

When the nucleolus is used to measure the power structure, we again obtain a very substantial redistribution through the full liberalization. Surprisingly however, with the nucleolus outside producers do not benefit from 'cutting out the middlemen'. All the losses of the local champions are transferred to the European customers.

The focus on the power of external producers and use of a cooperative approach

[44] So far the liberalization of the gas sector has moved at low speed. According to our analysis the move from a fragmented to an integrated market has small impact on the power distribution in the Gas sector, which is in line with the limited empirical evidence (Haase and Bressers (2010)). However, the next step towards a fully liberalized market has a large potential to enhance the power of outside producers. This might justify protective measures, such as the strategic diversification of gas supplies as analyzed in Hubert and Cobanli (2014), or the use of trade quotas as discussed in Ikonnikova and Zwart (2014).

separates this paper from previous literature on gas market reforms mentioned above. Hubert and Ikonnikova (2011a), Hubert and Ikonnikova (2011b) and Hubert and Suleymanova (2008) pioneered the use of cooperative game theory in the analysis of the gas industry. However, these papers consider a small sector in North-Western Europe and focus on pipeline investments not on access rights. For this paper we develop a much larger model of the natural gas network, covering the whole of Europe and its major suppliers. Variants of this model are used in Hubert and Orlova (2014a) to analyze the regional effect of market integration and the incentives for mergers and cartels and in Hubert and Cobanli (2014) to investigate strategic pipeline investments. The present paper differs (a) in its focus on the distribution of power between customers and local champions and (b) in its analysis of access to distribution systems.

Looking beyond gas and regulation, the paper contributes to a small strand of literature applying cooperative game theory to the analysis of vertical structures. There exists a very substantial theoretical literature on the various solutions for cooperative games, their relations among each other, possible non-cooperative foundations, and computational issues. But with the notable exception of voting games and the allocation of common cost, the latter being mainly normative, this sophisticated theory had little impact on applied research. As a result, little is known about the practical differences of the various solution concepts, their intuitive appeal in the understanding of power relations, and their predictive power. Our results for access regulation in the European gas network show that the Shapley value nicely corresponds to the intuition that 'cutting out the middlemen' benefits both sides of the market. The nucleolus in contrast, allocates all the increase in power only to one side of the market, the customers.

2.2 The Approach

In this section we briefly describe the representation of the physical network, the cooperative game, the solution concepts and the model calibration. More details are given in the technical appendix at `http://www.ms-hns.de/research_gas` and at `http://www.ms-hns.de/paper-network-access`. While addressing a different topic, this paper uses the same approach as Hubert and Orlova (2014a), Hubert and Cobanli (2014), and Cobanli (2014). Hence, there is considerable overlap with the corresponding sections in these papers, and the reader may skip it if familiar with any of the other papers.

2.2.1 The Model

Network.

The model of the Eurasian gas network consists of a set of nodes R, which may be production sites R_P , customers R_C, or pipeline inter-connectors R_T, and a set of directed links L. Each link $l = \{i, j\}, \ i \neq j \in R$ connects two nodes. Let f_{ij} denote gas flows, with negative values indicating a flow from j to i. For those links, which connect a producer to the network or the network to a customer, flows have to be positive ($f_{ij} \geq 0, \ \forall\, i \in R_P$ or $j \in R_C$). Links between inter-connectors which represent the trunk pipelines can be used in both directions. For each link $\{i, j\}$ we have a capacity limit k_{ij} and link specific transportation cost $T_{ij}(f_{ij})$, which includes production cost in case of $i \in R_P$. For existing capacities, transportation costs consist only of operation costs, because investment costs are sunk. When allowing for investments to increase k_{ij}, the annualized capital costs for new capacities are added to the transportation costs. Each customer is connected through a single dedicated link to the network. So consumption at node $j \in R_C$ is equal to f_{ij}. The inverse demand is $p_j(f_{ij})$.

Game.

The inter-dependencies among the players can be represented by a game in value function form (N, v), where N is the set of players and the value (or characteristic) function $v : 2^{|N|} \rightarrow R_+$ gives the maximal payoff, which a subset of players $S \subseteq N$, also called coalition, can achieve. The legal and regulatory framework determines the access rights of the various players. Access to the link $\{i, j\}, \ i \in R_P$ is equivalent of having access to production at i. Access to $\{i, j\}, \ j \in R_C$ yields access to customer j. For any coalition $S \subseteq N$ we have to determine to which links $L(S) \subseteq L$ the coalition S has access. The value function is obtained by maximizing the joint surplus of the players in S using the gas-flows in the pipelines which are accessible for S:

$$v(S) := \max_{\{f_{ij} | \{i,j\} \in L(S)\}} \left\{ \sum_{\{i,j\} \in L(S),\, j \in R_C} \int_0^{f_{ij}} p_j(z)dz - \sum_{\{i,j\} \in L(S)} T_{ij}(f_{ij}) \right\} \tag{2.1}$$

subject to

$$\begin{array}{rcll} \sum_i f_{it} & = & \sum_j f_{tj}, & \forall\, t \in R_T(S) \quad \text{(node-balancing)} \\ |f_{ij}| & \leq & k_{ij}, & \forall\, \{i, j\} \in L(S) \quad \text{(capacity constraints)} \\ f_{ij} & \geq & 0, & \forall\, i \in R_P \text{ or } j \in R_C \quad \text{(non-negativity)} \end{array}$$

The value function captures the essential economic features, such as the geography of the network, different cost of alternative pipelines, demand for gas in the different regions, production cost, etc. It also reflects the institutional framework, such as ownership titles and access rights through its dependence on $L(S)$. By defining a new system of access rights, each step of reform yields a new value function.

Solutions.

Cooperative game theory has developed a number of solutions for games in value function form. In the following we emphasize the Shapley value (Shapley (1953)), which assigns a unique payoff to each player, ϕ_i, $i \in N$. It is based on the contribution $v(S \cup i) - v(S)$ which a player i can make to the various subgroups of other players S. The Shapley Value nicely captures the intuition, that a player's payoff from cooperation, interpreted as his power in the game, should increase with his importance for other players, as measured by the value of his contributions. Formally, it is calculated as player i's weighted contribution:

$$\phi_i = \sum_{S: i \notin S} P(S)\,[v(S \cup i) - v(S)] \tag{2.2}$$

where $P(S) = |S|!\,(|N| - |S| - 1)!/|N|!$ is the weight given to S. For convenience ϕ denotes the vector of Shapley Values and $\phi_S = \sum_{i \in S} \phi_i$ the sum of Shapley Values of a coalition S.

The other major solution concept for the cooperative games is the core. Let x be a payoff vector and $x_S := \sum_{i \in S} x_i$ be the total payment to the members of S. Here, we consider only payoff vectors x which are efficient $\sum_{i \in N} x_i = v(N)$ and individually rational $x_i \geq v(i)$, so called imputations I. The excess e is the difference between what a coalition can achieve alone and what it receives $e(S, x) := v(S) - x_S$. The larger the excess is, the 'worse' is the coalition doing under x. If the excess is positive, the coalition should reject (block/veto) a proposed x, because it can do better on its own. The core is the set of imputations for which no coalition has positive excess: $c(\epsilon) := \{x : e(S, x) \leq 0,\ \forall S \subset N\}$.

If not empty, the core is typically not unique and its characterization through $2^{|N|} - 2$ inequalities is cumbersome if the number of players is large. Instead, we use the nucleolus, which always exists, is unique and in the core if this is not empty. Moreover it can be interpreted as the lexicographic center of the game (Maschler et al. (1979)). Originally, the nucleolus has been proposed as the imputation which minimizes 'inequity' among coalitions (Schmeidler (1969)). Let $\theta(x)$ be the vector of excesses arranged in decreasing order for a payoff vector x and let $\preceq$ stand for lexicographical smaller. The nucleolus, denoted μ, is defined as the imputation which minimizes the excess in lexicographic ordering: $\mu := \{x \in I : \theta(x) \preceq \theta(y) \text{ for all } y \in I\}$. It can be computed by solving a nested sequence of linear optimization problems. First excess is made minimal for the coalitions, which are doing worst. Then excess is reduced for the coalitions, which come second, and so on.[45]

2.2.2 Specification & Calibration

Regional scope and players.

The biggest practical challenge is the calculation of the value function, for which we have to solve $2^{|N|} - 1$ optimization problems. In order to economize on computing time we have to limit the number of players $|N|$. So we leave out producers which appear to be of minor strategic relevance and aggregate European regions into larger areas.

As to outside producers we focus on Russia, Norway, Algeria, and Libya which together cover about 85% of the gas imports into the European Union.[46] We also account for Belarus and Ukraine, which are major transit countries for Russian gas. These producers and transit countries are represented by one player each.

We collect Austria, Czech Republic, Slovakia, Hungary, Slovenia, and Serbia in one region called "Center-East". The countries in the region exhibit similar consumption and import dependency patterns. With very little alternative supplies the region depends with 80 % of its imports on Russia. While the pipeline networks are largely privatized, some owned by Western importers, the Austrian OMV can be seen as the dominant private supplier in the region. Germany, Switzerland, Denmark and Luxembourg are bundled to "Center". In terms of consumption the region is clearly dominated by Germany, which is also home of large Gas suppliers E.ON-Ruhrgas and Wintershall. The region covers more than three quarters of gas consumption by imports, but its pipeline imports are well diversified between Russia (35%), Norway (34%) and Netherlands (26%). We aggregate France, Spain and Portugal in a region labeled "South-West", which hosts two large champions, Gaz de France and

[45] In the terminology of operation research computation of the nucleolus is a 'hard' problem for which we use an algorithm proposed by Potters et al. (1996) who also provided us with the MATLAB code.

[46] Figures are calculated for the year 2009 from BP (2010).

ENAGAS. More than half of the gas consumption in the region is covered by LNG imports. Pipeline imports are diversified between Norway (39%), Algeria (18%) and Russia (18%).

For Center-East, Center, and South-West, as well as for Netherlands and Italy, we distinguish explicitly between a fictive regional champion and a fictive regional customer. Only for these five regions, which together account for 71 % of the EU's gas consumption, we can analyze how liberalization affects customers as compared to champions. Having only one player on each market side, we abstract from competition between different customers or different champions within the region.

There are four more regions which are represented by one player only. Belgium, Poland and UK correspond to their respective countries. Finally, we collect Romania, Bulgaria, Greece and Turkey in a region called "Turkey & Balkan". The region has only weak links to other European regions and imports mainly Russian gas. For these regions we can only identify 'regional' effects. With these aggregations and simplifications we are left with 20 players, hence a little more than a million possible coalitions.

Regarding access rights, we assume that outside EU every country has unrestricted control over its pipelines, customers and gas fields. Hence a coalition, which does not include Russia, has no access to Russian gas. If it does not include Ukraine, Ukraine's transit pipelines cannot be used to transport gas from Russia to Europe etc. Access to resources and consumers within Europe depends on the regulatory regime. Under any scenario the local champion enjoys exclusive ownership of local gas production and import terminals for liquefied natural gas (LNG-imports). In a *fragmented market* we need the local champion also to access transit pipes and local customers. In an *integrated market*, European transit pipelines are available to all players, but a local customer can only be reached with the collaboration of the local champion. Only in the *fully liberalized* market, the local champion is reduced to his role as local producer and LNG-importer, while local customers can access all suppliers on their own.

Temporal scope / network flexibility.

We assume a stationary environment with constant demand, technology and production cost etc. The value of a coalition, nevertheless, depends on the temporal scope of the model. In the short run, the architecture and the capacities of the network are given, but in the long run the network is flexible.

First we consider a rather short time horizon of one year up to perhaps three years. Such a period allows to ignore the seasonal pattern of demand and the possibility of gas storage.[47] It is also long enough to convert existing pipeline to bidirectional usage but too short to build new pipelines or develop new fields. We refer to this variant as the 'status-quo' variant, because pipeline capacities are static. It can also be interpreted as a 'shortsighted' assessment of power, because the effects of adjustments which take longer than two or three years to be achieved are simply ignored.

We reckon that decision makers, when assessing bargaining power, may look beyond such a short period. To assess the robustness of our results, we also consider a longer time span. Here we envisage a scenario in which transport capacities can be increased so that the network capacity is flexible. As these investments will take at least a couple of years to become effective, we consider a period starting some three years ahead from the date for which we assess the power structure. We refer to this variant as flexible network, because a coalition can use (almost) all investment possibilities to enhance its value. It can be also considered as a 'farsighted' assessment of power because it ignores the period which is needed to bring new capacities on stream.[48]

Cost and demand.

The details of the numerical calibration are given in a technical appendix. Here we outline only the main principles. We assume piece-wise linear production cost for each producer and linear demand functions with the same intercept for all regions. The model is calibrated using data on consumption in the regions and flows between the regions from 2009. Production cost have a common base, to which we make minor regional adjustments to replicate flows in 2009. The slope parameters of demand are estimated as to replicate the consumption in 2009. The most important implication of our calibration of demand in relation to cost is that the pipeline

[47] In Europe storage facilities help to smooth seasonal patterns of consumption, but at present they are too low to act as a strategic reserve for longer periods.

[48] The distinction between status-quo/shortsighted and flexible/farsighted is borrowed from Hubert and Ikonnikova (2011b). It is worth remembering that many gas contracts are long-term covering periods from 5 to 20 years, so we would expect that the conditions agreed on, reflect long term considerations. On the other hand, the further one projects into the future, the more uncertain the prospects become, so that the clearer short term options may exert a stronger influence on relative power.

system as existing in 2009 is sufficient. Given the willingness to pay and the cost of supplying gas the network is able to deliver the efficient amount of gas into the different consumption nodes. Nevertheless, the options to change the network will affect bargaining power in a long-term assessment, because it enables coalitions, which do not have access to the full network, to adjust their sub-network to their needs.

The calibration ensures that the main difference between customers is the size as measured by total consumption, and network connection on which we have solid information. The main difference between producers is production capacity and pipeline connections to the markets, for which data are good, and not differences in wellhead production cost, which are difficult to estimate. The overall size of the surplus is largely determined by our assumption on the difference between the common supply cost and the common demand intercept. We discuss the robustness of our results with respect to changes in these parameters at the end.

2.3 Network Access and Power

We imagine the liberalization of the European market for natural gas to be achieved in two steps: first, by opening access to high pressure trunk pipes, and second by liberalizing access to low pressure distribution networks. So we compute the value function for three access regimes: the fragmented market v^0, the integrated market v^1 and the fully liberalized market v^2. Then we solve the games, either with the Shapley value ϕ or the nucleolus μ, and compute three differences: the impact of trunk pipe liberalization ($\Delta\phi^1 = \phi(v^1) - \phi(v^0)$), the incremental impact of access to distribution networks ($\Delta\phi^2 = \phi(v^2) - \phi(v^1)$), and the total impact of the ongoing reforms ($\Delta\phi^{12} = \phi(v^2) - \phi(v^0)$). The corresponding values for the nucleolus are $\Delta\mu^1$, $\Delta\mu^2$, and $\Delta\mu^{12}$.

Before we look at the details for individual players, we assess the importance of the reforms. As liberalization will benefit some of the market participants while hurting others, its overall impact can be measured by the fraction of the surplus, which is redistributed as a result of the reforms. Summing up the gains for those who benefit (or the losses of those who are hurt) we obtain one figure R^j, $j \in \{1, 2, 12\}$, for each of the three differences mentioned above.[49]

[49] Our focus is on the impact of liberalization, hence the differences in the power index. These differences are the same whether we normalize the game or not. When looking at the fraction of surplus which is redistributed, we refer to the surplus of the non-normalized game.

Table 2.1: Overall Impact (Shapley Value)

	Redistribution in per cent of initial share		
	step 1: transmission *fragmented to integrated market*	step 2: distribution *integrated to liberalized market*	both together *fragmented to liberalized market*
All players $100 * R^j / v^0(N)$	2.0	12.4	13.0
European players only $100 * R^j / \phi_{EU}(v^0)$	4.0	25.4	26.6

We first report our point estimates for one particular calibration of the model: the short-sighted or status-quo variant, in which pipeline capacities are given. We also assume a rather large difference of 1500 Euro between demand intercept and supply cost. Then we briefly discuss the robustness of the results as to changes of parameters and scope. All figures are rounded to the first decimal.

2.3.1 Shapley Value

Table 2.1 displays the redistribution as a percentage of the initial rent of all players $v^0(N)$ and as a percentage of the joint shares of the EU players before the reform, $\phi_{EU}(v^0)$. The figures show that the total impact of the reforms on the European gas market will be quite substantial. The rent which some players lose, and others gain, through the full liberalization adds up to 13% of the total rent or to one quarter of the joint rents of the European players. The second step, the liberalization of access to distribution networks, appears to be decisive. Its incremental impact is six times larger than that of the initial step, the opening of access to trunk-pipes.[50] Liberalization had progressed slowly during a time when the European gas market was subjected to several outside shocks, first the long international boom before 2008, then the fallout of the financial crisis, then the shale gas revolution. The comparably modest impact of the first step will make it difficult to trace results in empirical data so far (Haase and Bressers (2010)). But from the failure to do so one must not conclude that future steps have little impact as well.

The two steps differ not only in their overall relevance, they also affect the various players in markedly different ways. In table 2.2 we report the gains and losses,

[50] Since the direction of redistribution is reversed in some cases, the final volume of redistribution is not the sum of the two incremental effects.

Table 2.2: Liberalization and Power-Structure (Shapley Value)

	Change of Shapley Value [percentage of all gains]		
	step 1: transmission *fragmented to integrated market* $100 * \Delta\phi^1/R^{12}$	step 2: distribution *integrated to liberalized market* $100 * \Delta\phi^2/R^{12}$	both together *fragmented to liberalized market* $100 * \Delta\phi^{12}/R^{12}$
Outside Countries			
Russia	−7.0	14.7	7.7
Belarus	3.1	−0.4	2.7
Ukraine	1.9	0.4	2.4
Algeria	−0.5	6.8	6.3
Libya	0.0	1.6	1.7
Norway	0.9	11.6	12.5
Netherlands	0.2	1.3	1.5
champion	0.3	−6.6	−6.3
customers	−0.1	7.9	7.8
Center-East[a]	1.4	−5.3	−3.9
champion	−0.6	−13.0	−13.6
customers	1.9	7.7	9.6
Italy	3.8	−9.6	−5.8
champion	1.1	−23.1	−21.9
customers	2.7	13.4	16.1
Center[b]	−5.9	−12.6	−18.5
champion	−6.6	−30.8	−37.4
customers	0.7	18.2	18.9
South-West[c]	1.5	−7.8	−6.3
champion	0.7	−19.7	−19.0
customers	0.7	11.9	12.6
Poland	0.1	−0.6	−0.4
Belgium	−0.4	−1.0	−1.4
United Kingdom	0.1	1.2	1.3
Turkey & Balkan[d]	0.7	−0.3	0.4
all champions	−5.1	−93.1	−98.2
all customers	5.9	59.1	65.1
European Union[e]	1.5	−34.7	−33.2

[a] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

[e] Including Turkey

now measured in percentage of the overall redistribution of the full reform (R^{12}). For convenience we also report the aggregated figures for some groups of players (given in italics). In the first column we give the figures for the impact of opening access to trunk pipes. The move from a fragmented to an integrated market figures yields rather heterogeneous effects. Within Europe, we observe the strongest effect for the champion in *Center*: a loss of well over six percentage points. The region is well connected to competing suppliers, Russia, Norway, Netherlands, hence there is little to gain from improved access to additional suppliers. At the same time its strategic location with respect to gas shipments earned him substantial transit rents, which are now lost.[51] Champions which are located more at the periphery, e.g. in Italy or in the South-West, gain more from improved access to suppliers than they suffer from the loss of transit rents. The customers in the Union tend to gain. Altogether they improve by almost 6 per percentage points, which is a little more than what the champions lose. The only exception are the customers in the Netherlands, which, given ample local supplies, enjoyed a privileged position in the fragmented market.

Considering customers and champions together, we find some regional redistribution within the Union. The *Center* loses power while Italy and the South-West gain power. The liberalization of trunk pipes becomes effective only for those within the jurisdiction of the EU. Access to pipelines in Russia, Ukraine and Belarus is still exclusive. Nevertheless we find a rather strong regional redistribution outside the Union. Russia loses 7 percentage points, the largest figure in this column. This big loss of an outside producer is largely compensated by gains of Ukraine and Belarus, as well as Norway, Russia's strongest competitor. Belarus has no own natural gas production and Ukraine consumes much more than it produces. Both countries totally depend on Russia for their very substantial imports. With the liberalization of shipment through the EU they can more easily access gas from Norway, which increases their bargaining power vis-a-vis Russia.

Overall, the first step of reforms produces modest redistribution from champions to customers within the Union, but there is no rent leakage to outside countries. Instead, there is even a small gain of the Union.

[51] At first glance Center's role as a transit region may appear to be modest. With 4.3 bcm/a and 9.1 bcm/a gas flows through Center to France and to Italy, respectively, are not particular large. However, the region is Europe's most important *potential* gas hub. Whenever one of the major producers is taken out of the picture, Center becomes an important transit region. For more details see Hubert and Orlova (2014a).

The picture changes dramatically when moving on to the second step, the liberalization of access to the distribution systems. With the notable exception of transit regions such as Ukraine, Belarus and to a smaller extent Turkey& Balkan, the incremental impact of this step is much larger, sometimes by order of magnitude, and clearly dominates the total effect. Thus, we confine our interpretation to the last column in table 2.2, which describes the effect of both steps together.

Here we find a very clear pattern. All champions lose and their aggregated losses amount to 98 percent of the total volume of redistribution. Essentially, the full liberalization of pipeline access in the EU has one big effect: it destroys much of the market power of the established regional champions, which apparently depended more on controlling access to local customers than on controlling transit. This is true even for those champions which gained from improved access to alternative supplies or additional customers during the first phase of the reform, such as Italien Eni. Its initial gain of 1.1 percentage points turns into a loss of 21.9 points, the second biggest loss of all. It is only surpassed by the Center's champion, whose initial loss of 6.6 points is amplified to a loss of 37.4 percentage points.[52]

Dismantling the power of regional champions is, first of all, to the benefit of the customers. In all the regions customers gain from full liberalization, often by order of magnitude more than from liberalizing only transit. With the exception of Netherlands, however, the customers gain less than the champions lose. On average, one third, of what is taken away from the champions does not end up with customers but leaks to players outside the Union, with Norway, Russia and Algeria being the main beneficiaries.[53] Even for Russia, which was quite badly hurt from opening transit pipelines, the losses turn into a substantial net gain. Being able to sell gas directly to its customers turns out to be much more valuable than the partial protection against competing suppliers, which it enjoyed in the fragmented market.

Taken together, these results suggest that the Commission's claim quoted in the introduction has some merit for the first step of reform. Liberalizing access to the high pressure transmission system strengthens the bargaining power of at least

[52]This last figure, however, has to be interpreted with care. As mentioned before, assuming only one champion for the central region is a rather strong simplification as we have at least two substantial players, E.ON-Ruhrgas and Wintershall, in reality. In addition, these players had only rather incomplete control of distribution networks before the reforms.

[53]Apart from that, there is only very limited regional redistribution from Poland and Belgium on one side to the UK and the Balkans on the other. These are regions, for which we did not separate between customers and champions.

Table 2.3: Robustness: Overall Impact (Shapley Value)

	Redistribution in per cent of initial share					
	step 1: transmission *fragmented to integrated market*		step 2: distribution *integrated to liberalized market*		both together *fragmented to liberalized market*	
	min	*max*	*min*	*max*	*min*	*max*
All players $100 * R^j / v^0(N)$	1.9	2.0	12.0	13.4	12.6	13.7
European players only $100 * R^j / \phi_{EU}(v^0)$	3.8	4.0	24.7	27.2	26.0	27.9

some European Energy companies. However, it is grossly misleading for the second step. The liberalization of access to the distribution systems clearly weakens the old incumbents through tougher competition both among each other as well as with outside producers. If power is assessed with the Shapley value, we also find support for concerns about the dominance of outside producers. For every two Euros which European customers gain in bargaining power, one Euro leaks to players outside the Union.

Robustness.

In this section we briefly assess the robustness of the previous results by considering three more variants. First, we changed the temporal scope of the analysis by analyzing a 'flexible' network, in which the capacities of the pipelines can be increased through investment. This change does not affect the overall surplus from the gas trade, but it has a considerable impact on the relative bargaining power of the different players. Second, we reduced the difference between the common supply cost and the demand intercept, hence the absolute surplus from gas trade, by two thirds, both for the static and the flexible network. We express all our results as percentage of surplus, which tends to neutralize the re-scaling of the surplus. Nevertheless, the power-structure is affected because transportation and investment cost have a larger impact when the difference between demand intercept and supply cost is reduced.

Instead of going in detail through all these variants, we simply report the minimal and maximal values achieved in any of the four variants in tables 2.3 and 2.4, which correspond to tables 2.1 and 2.2, respectively. The differences between the maximal values in any of the variants and the corresponding minimal values are sur-

Table 2.4: Robustness: Power-Structure (Shapley Value)

	Change of Shapley Value [percentage of all gains]					
	step 1: transmission *fragmented to integrated market*		step 2: distribution *integrated to liberalized market*		both together *fragmented to liberalized market*	
	min	*max*	*min*	*max*	*min*	*max*
Outside Countries						
Russia	−7.2	−6.9	14.5	16.7	7.5	9.5
Belarus	3.1	3.2	−0.8	−0.4	2.2	2.7
Ukraine	1.8	2.0	−0.9	0.4	0.8	2.4
Algeria	−0.5	0.1	5.1	6.9	5.2	6.5
Libya	0.0	0.2	1.3	1.7	1.5	1.8
Norway	0.9	1.1	10.0	12.1	10.9	13.1
Netherlands	0.2	0.2	1.0	1.6	1.2	1.8
champion	0.3	0.4	−7.3	−6.2	−7.0	−5.8
customers	−0.2	−0.1	7.8	8.3	7.6	8.2
Center-East[a]	1.4	1.9	−5.3	−4.6	−3.9	−2.7
champion	−0.6	0.2	−13.0	−12.5	−13.6	−12.3
customers	1.8	2.0	7.7	7.9	9.6	9.7
Italy	2.8	3.8	−9.7	−8.4	−6.0	−5.6
champion	0.5	1.1	−23.1	−22.4	−22.0	−21.7
customers	2.2	2.7	13.3	14.0	15.9	16.1
Center[b]	−6.1	−5.7	−12.6	−11.2	−18.7	−16.9
champion	−6.8	−6.3	−30.8	−29.9	−37.5	−36.2
customers	0.6	0.7	18.1	18.8	18.8	19.3
South-West[c]	1.1	1.5	−7.9	−7.3	−6.4	−6.3
champion	0.6	0.7	−21.8	−19.7	−21.2	−19.0
customers	0.5	0.8	11.9	14.5	12.6	14.9
Poland	−0.1	0.1	−0.6	−0.5	−0.6	−0.4
Belgium	−0.5	−0.2	−1.1	−0.8	−1.6	−1.0
United Kingdom	−0.1	0.1	0.8	1.2	0.7	1.3
Turkey & Balkan[d]	0.7	0.9	−0.5	−0.3	0.4	0.5
all champions	−5.3	−4.6	−93.9	−92.6	−98.5	−97.9
all customers	4.9	6.0	58.8	63.3	64.7	68.2
European Union[e]	0.7	1.5	−34.9	−31.3	−33.9	−30.2

[a] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

[e] Including Turkey

Table 2.5: Overall Impact (nucleolus)

	Redistribution in per cent of initial share		
	step 1: transmission *fragmented to integrated market*	step 2: distribution *integrated to liberalized market*	both together *fragmented to liberalized market*
All players $100 * R^j/v^0(N)$	2.0	16.1	18.1
European players only $100 * R^j/\mu_{EU}(v^0)$	4.0	31.8	35.7

prisingly small. With minor modifications all previous statements could be repeated independently of whether we take the largest or smallest value.

Take for example the overall impact of full liberalization (table 2.3). Depending on the variant, it redistributes between 26 and 27.9 per cent — or roughly a quarter of the joint rent of all European players. The overall effect is clearly dominated by the impact of opening access to distribution systems, the incremental impact of which is about six times larger than that of the first step. If we look at the power structure (table 2.4) we again find that the players in the Union gain between 0.7 and 1.5 percentage points from the first step — a negligible amount. In contrast, they lose between 30.2 and 33.9 points, i.e. roughly a third, from the full implementation of reforms.

These observations suggest that our results for the change in power as measured by the the Shapley are robust with respect to changes in the parameters of the model. We turn next to the question, whether they are also robust with respect to the solution concept.

2.3.2 Nucleolus

Opening access to pipelines will increase the value for some coalitions. Others might be unaffected, but the value of a coalition will never be reduced. Hence, the excess will (weakly) increase and the core will be compressed. Unfortunately, the core is characterized by over a million of inequalities which makes it difficult to identify patterns of change. Instead, we use the nucleolus, a unique point within the core, as an indicator for the impact of liberalization.

The pattern of the aggregated impact looks similar for the nucleolus and for the Shapley value (compare tables 2.5 and 2.1). The impact of the first step is essen-

Table 2.6: Liberalization and Power-Structure (nucleolus)

	Change of nucleolus [percentage of all gains]		
	step 1: transmission *fragmented to integrated market* $100 * \Delta\mu^1/R^{12}$	step 2: distribution *integrated to liberalized market* $100 * \Delta\mu^2/R^{12}$	both together *fragmented to liberalized market* $100 * \Delta\mu^{12}/R^{12}$
Outside Countries			
Russia	−4.9	0.0	−5.0
Belarus	0.1	0.0	0.1
Ukraine	1.7	0.0	1.7
Algeria	0.1	0.0	0.1
Libya	0.1	0.0	0.1
Norway	0.2	0.0	0.2
Netherlands	0.1	0.0	0.1
champion	−1.4	−12.6	−14.0
customers	1.4	12.6	14.1
Center-East[a]	0.3	0.0	0.3
champion	−1.0	−10.8	−11.8
customers	1.3	10.8	12.1
Italy	0.0	0.0	0.1
champion	−1.6	−19.7	−21.3
customers	1.6	19.7	21.4
Center[b]	−0.3	0.0	−0.3
champion	−2.1	−27.3	−29.5
customers	1.9	27.4	29.2
South-West[c]	0.1	0.0	0.1
champion	0.0	−18.3	−18.3
customers	0.1	18.3	18.4
Poland	0.0	0.0	0.0
Belgium	0.0	0.0	0.0
United Kingdom	−0.2	0.0	−0.2
Turkey & Balkan[d]	2.6	0.0	2.6
all champions	−6.0	−88.8	−94.9
all customers	6.3	88.9	95.1
European Union[e]	2.7	0.1	2.8

[a] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

[e] Including Turkey

Table 2.7: Robustness: Overall Impact (nucleolus)

	Redistribution in per cent of initial share					
	step 1: transmission *fragmented to integrated market*		step 2: distribution *integrated to liberalized market*		both together *fragmented to liberalized market*	
	min	*max*	*min*	*max*	*min*	*max*
All players $100 * R^j / v^0(N)$	0.9	2.0	15.3	16.6	16.6	18.1
European players only $100 * R^j / \mu_{EU}(v^0)$	1.8	4.0	30.7	32.7	33.2	35.7

tially of equal magnitude and in both cases the second step appears decisive. For the nucleolus the increment of the second step is even more significant, redistributing 16.1 per cent of total surplus instead of 12.4. Moreover for the nucleolus, the two steps work into the same direction, wheres there was some partial offset under the Shapley value. As a result, the aggregate impact of both steps together is stronger. If power is measured with the nucleolus, redistribution through full liberalization, is equal to 18.1 per cent of the total surplus, or 35.7 per cent of the joint share of the EU players.

A closer look at the power structure, however, reveals striking differences between the two solutions (compare tables 2.6 and 2.2). The impact of the first step, free access to transit pipelines, is still similar. With the nucleolus the champions lose 6 percentage points compared to 5.1 under the Shapley value. Customers gain 6.3 compared to 5.9. There is some redistribution between regions resulting in a gain of 2.7 percentage points by the European Union. As before, Russia is the biggest single loser, but the effect on outside producers and transit countries tends to be smaller in magnitude.

The surprising differences come from the liberalization of access to distribution systems, hence, customers. For the nucleolus, there are essentially no effects on outside producers and transit countries, while there is a massive redistribution of surplus from champions to customers within the Union. The effect of the second step on customers and champions is again larger by order of magnitude. For example, the Italian champion loses 1.6 points with the first step and another 19.7 points with the second; for Center the corresponding losses are 2.1 and 27.3. In contrast to the Shapley value, whatever the champions lose in the second step is now gained by their respective customers. There are no additional regional effects within the

Table 2.8: Robustness: Power-Structure (nucleolus)

	Change of Nucleolus [percentage of all gains]					
	step 1: transmission *fragmented to integrated market*		step 2: distribution *integrated to liberalized market*		both together *fragmented to liberalized market*	
	min	*max*	*min*	*max*	*min*	*max*
Outside Countries						
Russia	−4.9	−2.8	−0.2	0.0	−5.0	−2.8
Belarus	0.1	0.2	0.0	0.0	0.1	0.2
Ukraine	0.4	1.7	0.0	0.0	0.4	1.7
Algeria	0.1	0.4	−0.1	0.0	0.1	0.3
Libya	0.1	0.2	0.0	0.0	0.1	0.3
Norway	0.2	0.8	0.0	0.0	0.2	0.7
Netherlands	0.1	0.2	0.0	0.0	0.1	0.2
champion	−1.4	0.0	−13.1	−12.6	−14.0	−13.0
customers	0.1	1.4	12.6	13.0	13.2	14.1
Center-East[a]	0.2	0.3	0.0	0.0	0.2	0.3
champion	−1.0	0.2	−11.2	−10.8	−11.8	−11.0
customers	0.1	1.3	10.8	11.2	11.3	12.1
Italy	−0.3	0.0	0.0	0.0	−0.2	0.1
champion	−1.6	−0.5	−20.4	−19.7	−21.3	−20.9
customers	0.2	1.6	19.7	20.4	20.7	21.4
Center[b]	−0.8	−0.3	0.0	0.1	−0.8	−0.3
champion	−2.1	−1.3	−28.3	−27.3	−29.8	−29.2
customers	0.5	1.9	27.4	28.3	28.9	29.2
South-West[c]	0.1	0.3	0.0	0.0	0.1	0.3
champion	−0.2	0.1	−21.9	−18.3	−22.1	−18.3
customers	0.1	0.3	18.3	22.0	18.4	22.2
Poland	0.0	0.1	0.0	0.0	0.0	0.1
Belgium	0.0	0.1	0.0	0.0	0.0	0.1
United Kingdom	−0.5	−0.2	0.0	0.0	−0.5	−0.2
Turkey & Balkan[d]	1.6	2.6	0.0	0.1	1.7	2.6
all champions	−6.0	−1.6	−94.7	−88.8	−97.0	−94.6
all customers	1.2	6.3	88.9	94.9	94.4	97.1
European Union[e]	0.8	2.7	0.1	0.3	1.1	2.8

[a] Austria, Czech Republic, Slovakia, Hungary, Slovenia and Serbia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

[e] Including Turkey

Union or spillovers to players outside. In spite of a dense pipeline network, liberalizing access to customers appears to be a local affair under the nucleolus. It affects the power distribution only in the respective region. Although, access liberalization 'cuts out the middlemen', outside producers and transit countries cannot benefit, if market power is measured by the nucleolus.

Robustness.

We again check the robustness of the results with respect to changes in demand and network flexibility. As before we report only the smallest and largest values of all variants (tables 2.7 and 2.8). While the numbers change slightly, all qualitative statements of the previous section remain. In particular, the rent, which is redistributed through the full liberalization constitutes roughly a third of the joint share of EU players for all scenarios and the second step is clearly decisive. The smaller regional effects result entirely from liberalizing transit, while opening access to customers redistributes power at a large scale, but only within the region.

2.4 Conclusion

Opening access to bottleneck facilities such as electric power grids, rail tracks, communication lines and pipeline systems has been a corner stone of market liberalization and deregulation of network based industries throughout the last decades. Moreover, in the European Union, open network access is also necessary to overcome the national and regional fragmentation of the respective industries, hence, for the establishment of a common market. The general thrust has been to limit public regulation to the network itself, a natural monopoly, and allow for free competition in the provision of services or commodities using the network. It is argued that such liberalization increases the efficiency of the industry and that customers gain from enhanced competition between service providers.

However, the natural gas industry in Europe is peculiar in the sense that a small number of external suppliers such as Russian Gazprom or Norwegian Statoil will retain substantial market power through their control of gas fields beyond the jurisdiction of the EU. Given this dependency on few outside producers, a policy which weakens the national champions within the Union might enhance the market power of external suppliers. The Commission argues to the contrary, claiming that European energy companies might even gain from better access to customers and more diverse supply options.

In this paper we studied the impact of liberalization on the balance of power between regional champions, customers and outside producers differentiating between opening access to trunk pipes and additionally liberalizing access to distribution systems, hence customers. Access to trunk pipes, here considered to be the first step of reform, allows for free transit of gas within EU and moves the industry from a fragmented to an integrated market. In a second step access to distribution networks is also opened which establishes a fully liberalized market. In contrast to earlier studies, we use cooperative game theory which allows us to derive the power of the players endogenously from their role in the network without resorting to ad hoc assumptions about the nature of the strategic interaction. All our results are reasonably robust with respect to changes in the model calibration but it makes a substantial difference whether we assess network power with the Shapley Value or with the nucleolus.

For the Shapley value we find a heterogeneous impact of the first step of reform on the power structure. Overall, there is modest redistribution from champions to customers, but there is no leakage of power to outside producers. The picture changes dramatically with the second step. The incremental impact of the liberalization of access to customers clearly dominates the total effect. In a fully liberalized market the power of all European champions is decreased. Dismantling the power of champions is to the benefit of customers, but approximately one third of champions' losses leaks to external suppliers, whose power is increased substantially. The interpretation is straightforward. In a fragmented market, local champions secure their position as 'middlemen' through their control of pipelines. Liberalization essentially 'cuts out the middlemen' to the benefit of customers and external producers.

If we use the nucleolus as the power index, the pattern of power redistribution from the first step of reform is similar and again the second step turns out to be decisive. However, the pattern for the second step of reform is strikingly different. While local champions are again badly hurt, their losses are transferred one to one to their respective customers. For all other players the incremental effect of this step is essentially zero. As a result, outside producers would not benefit from liberalized access to customers if market power is assessed with the nucleolus. This finding clearly contradicts the intuition gained from the 'middlemen' story.

In a nutshell: independently of whether power is assessed with the nucleolus or the Shapley value, we do not find support for the claim that European energy companies might be strengthened through full liberalization of pipeline access. Quite to the contrary, under both solutions they will eventually lose a very substantial part of their original power. Whether powerful outside producers are able to appropriate part of this loss, in contrast, depends entirely on the solution concept.

It is beyond the scope of this paper, to investigate which of the two concepts yields better empirical predictions. As the liberalization developed slowly over the last fifteen years, it seems impossible to disentangle its impact from the effects of changes in LNG supplies, new pipeline links and the business cycle. There is, however, some evidence that the Shapley value is a better predictor for this industry obtained from transit agreements between Russia, Ukraine and Belarus (Hubert and Ikonnikova (2011b)) and from recent investments in strategic pipelines (Hubert and Cobanli (2014)). Hence, the possibility that the power of external producers is enhanced by Europe's liberalization of pipeline access is not to be easily dismissed.

Appendix B

B.1 Calibration

For this paper the explanation of the calibration is the same as for the paper ”Competition or Countervailing Power for the European Gas Market”. To avoid repetition of the text, we report only tables.

Table B.1: Pipeline Network: Consumption links

Links		Consumption	Slope		Players
			baseline scenario	low surplus	needed
		[bcm/a]	$a = 1500$	$a = 500$	for access[a]
from	to	f_{ij}	b_j	b_j	
Russia	RussiaC	426.4	3.5	1.2	Russia
Belarus	BelarusC	17.9	83.9	28.0	Belarus
Ukraine	UkraineC	53.3	28.1	9.4	Ukraine
Belgium	BelgiumC	16.9	88.9	29.6	Belgium
Poland	PolandC	16.0	93.8	31.3	Poland
UK	UKC	90.5	16.6	5.5	UK
Balkan[b]	BalkanC	20.2	74.3	24.8	Turkey & Balkan[c]
Turkey	TurkeyC	36.4	41.2	13.7	Turkey & Balkan
Regions with champion and customers					
Center[d]	CenterC	104.6	14.3	4.8	The champion and the customers in a region.*
Center-East[e]	Center-EastC	41.4	36.2	12.1	
Italy	ItalyC	75.6	19.8	6.6	
Netherlands	NetherlandsC	48.3	31.1	10.4	
South-West					
France	FranceC	44.1	34.0	11.3	
SpainPort[f]	SpainPortC	38.8	38.6	12.9	

[a] We list the players which are needed in the fragmented and the integrated market. We mark with a * those cases, where there is a change for the liberalized market. In the liberalized market only customers in a region are needed for the access to the consumption link.

[b] Romania, Bulgaria and Greece

[c] Balkan and Turkey are aggregated into one player 'Turkey & Balkan'.

[d] Germany, Denmark, Switzerland and Luxembourg

[e] Austria, Hungary, Czech Republic, Slovakia, Serbia, Slovenia

[f] Spain, Portugal

Table B.2: Pipeline Network: Production links

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operating Cost $c^P + \Delta_{ij}$ [€/tcm]	Players needed for access
Production outside EU					
RussiaP	Russia	650.8	550.5	c^P	Russia
NorwayP	Norway	99.4	99.4	$c^P - 7$	Norway
AlgeriaP	Algeria	77.7	77.7	$c^P - 5$	Algeria
LibyaP	Libya	15.9	15.9	$c^P - 8.8$	Libya
BelarusP	Belarus	0.2	0.2	0	Belarus
UkraineP	Ukraine	21.9	21.9	0	Ukraine
Production within EU					
BalkanP	Balkan	10.8	10.8	0	Turkey & Balkan[a]
BelgiumP	Belgium	0	0	0	Belgium
CenterEastP	CenterEast	4.9	4.9	0	champion in CenterEast
FranceP	France	0.9	0.9	0	champion in South-West[b]
CenterP	Center	23.7	23.7	0	champion in Center
ItalyP	Italy	8.1	8.1	0	champion in Italy
NetherlandsP	Netherlands	78.7	78.7	$c^P - 4.4$	champion in Netherlands
PolandP	Poland	5.8	5.8	0	Poland
SpainPortP	SpainPort	0	0	0	champion in South-West
TurkeyP	Turkey	0.7	0.7	0	Turkey & Balkan
UKP	UK	62.1	62.1	0	UK

[a] Balkan and Turkey are aggregated into one player 'Turkey & Balkan'.

[b] Spain, Portugal and France are aggregated into one region South-West.

Table B.3: Pipeline Network: LNG links

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operating[a] Cost $c^P + \Delta_{ij}$ [€/tcm]	Players needed for access
BalkanLNG	Balkan	0.8	0.8	$2c^P$	Turkey & Balkan[b]
BelgiumLNG	Belgium	3	3	$2c^P$	Belgium
FranceLNG	France	10.1	10.1	$2c^P$	champion in South-West[c]
CenterLNG	Center	0	0	$2c^P$	champion in Center
ItalyLNG	Italy	2.9	2.9	$2c^P$	champion in Italy
NetherlandsLNG	Netherlands	0	0	$2c^P$	champion in Netherlands
PolandLNG	Poland	0	0	$2c^P$	Poland
SpainPortLNG	SpainPort	28.5	28.5	$2c^P$	champion in South-West
TurkeyLNG	Turkey	6.1	6.1	$2c^P$	Turkey & Balkan
UKLNG	UK	10.1	10.1	$2c^P$	UK

[a] The global parameter c^P is set equal to 20. We give the unit cost for flows up to 75% of the capacity. For the remaining 25% of capacity the numbers are increased by 20%.

[b] Balkan and Turkey are aggregated into player 'Turkey & Balkan'.

[c] Spain, Portugal and France are aggregated into one region South-West.

Table B.4: Pipeline Network: Transit

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operating Cost c^T_{ij} [€/tcm]	Capacity Cost[a] c^K_{ij} [€/tcm/a]	Players needed for access[b]
Transit outside EU						
Russia	Belarus	100	49.2	2.1	-	Russia, Belarus
Russia	RussiaN	165	0	2.3	-	Russia
Russia	RussiaS	240	8.9	2.1	-	Russia
Russia	UkraineE	415	109.1	2.0	-	Russia, Ukraine
RussiaS	UkraineE	200	24.6	1.2	-	Russia, Ukraine
UkraineE	Ukraine	122	95.1	2.5	12.6	Ukraine
TurkeyE	Turkey	20	11.8	2.4	12.1	Turkey & Balkan[c]
Transit into (out of) EU						
Algeria	Italy	30.2	25.4	6.2	-	Algeria*
Algeria	SpainPort	12	9.2	4.5	-	Algeria*
Libya	Italy	11	9.0	4.7	-	Libya*
Belarus	Poland	33	31.3	1.4	8.9	Belarus*
Norway	Belgium	15	12.2	5.2	-	Norway*
Norway	France	18.3	15.0	5.9	-	Norway*
Norway	Center	46	29.2	5.2	-	Norway*
Norway	UK	46.4	24.0	4.9	-	Norway*
UkraineE	Balkan	31.3	16.5	3.4	4.0	Ukraine*
Ukraine	Center-East	105.8	77.0	1.9	9.5	Ukraine*
Ukraine	Poland	5	3.2	1.2	6.0	Ukraine*
RussiaN	Center	55	0	6.9	26.8	Russia*
Balkan	Turkey	16.3	8.9	1.8	9.2	Turkey & Balkan
RussiaS	Balkan	0	0	5.6	23.8	Russia*
RussiaS	Turkey	16	8.9	4.8	11.9	Russia, Turkey & Balkan
Transit within EU						
Belgium	France	30	14.9	0.8	4.0	In the integrated and the liberalized market access to transit pipelines within EU is free.*
Belgium	Center	26	1.0	0.6	3.0	
Center-East	Balkan	1.7	1.0	3.3	16.5	
Center-East	Center	77.8	18.4	2.4	12.0	
Center-East	Italy	37.0	21.3	2.7	13.5	
Center	France	28	4.3	1.4	7.1	
Center	Italy	20.2	9.1	3.5	17.3	
Netherlands	Belgium	53	10.7	0.5	2.6	
Netherlands	Center	80	11.7	0.6	3.0	
Netherlands	UK	15.3	7.0	1.0	3.5	
Poland	Center	31.4	24.4	3.2	16.1	
UK	Belgium	25.5	7.5	1.5	4.9	
France	SpainPort	4.7	1.1	3.2	15.8	
Balkan	Italy	0	0	3.9	28.5	
Out of regional scope						
Azerbaijan	RussiaS	0	0	3.8	-	Russia
Azerbaijan	TurkeyE	4.5	4.5	2.4	-	Turkey & Balkan
Iran	TurkeyE	7.2	7.2	1.2	-	Turkey & Balkan
Iraq	TurkeyE	0	0	1.7	-	Turkey & Balkan
Kazakhstan	Russia	0	0	5.1	-	Russia
Kazakhstan	RussiaS	32.3	32.3	3.6	-	Russia

[a] In the farsighted scenario we allow for investments in the links within EU and in the pipelines for Russian gas.

[b] We list the players which are needed in the integrated and the liberalized market. We mark with a * those cases, where there is a change for the fragmented market. Then either both players from the left column are needed or the champions in the respective regions are needed (if the champion was introduced explicitly for the region).

[c] Balkan and Turkey are aggregated into one player 'Turkey & Balkan'.

Chapter 3

Cooperative Solutions for the Eurasian Gas Network

Abstract

We relate three solutions for cooperative games, the Shapley value, the nucleolus and the core. We use an empirical case study, provided in Hubert and Orlova (2014b) to analyze the liberalization of network access in the European gas market. For these games the Shapley value is not in the core. To obtain a differentiated picture of the (in)stability of an allocation, we propose the $n\epsilon$-core which is a generalization of the strong ϵ-core, and define three stability measures. We find that the liberalization of network access increases the degree of instability of the Shapley value for all three metrics. The nucleolus is a unique point in the core, hence often used to characterize stable imputations. We show that liberalization compresses the core, but not always the nucleolus corresponds well to the shifts in the minimal and maximal values which players might receive in the core.

Keywords: Network Access, Natural Gas, Shapley Value, Nucleolus, Core
JEL class.: L1, L95

This paper is part of larger collaborative research project on the Eurasian gas network to which Onur Cobanli made essential contributions. I am very grateful to Prof. Dr. Franz Hubert, without whom this work would be impossible.

3.1 Introduction

In a recent series of papers, cooperative game theory has been used to assess the power structure in the network for natural gas and how it is affected by investments in new pipelines or changes in access regulation.[54] In this applied literature dis-aggregated network models are being used which are calibrated with real data. While the results are typically robust with respect to the assumptions on parameters, the findings turn out to be very sensitive depending on which solution from cooperative game theory, the Shapley value or the nucleolus, is used to obtain the power index. Moreover, the Shapley value appears to fit economic intuition and the empirical evidence better than the nucleolus (Hubert and Ikonnikova (2011b), Hubert and Cobanli (2014), Hubert and Orlova (2014b)). At the cost of some simplification, the basic story of these papers is one of 'cutting out the middlemen'. Either a new pipeline can bypass a transit country or access to an existing pipeline is liberalized. Intuition suggests that in both cases the owner of the bottleneck facility is weakened, while customers and gas producers would be strengthened.

For the most simple imaginable network, in which one pipeline connects a gas producer and a customer, this intuition is fully supported. In the initial situation the owner of the pipeline, acts as an indispensable middleman between the producer and the customer. If the access is liberalized, or a bypassing pipeline is built, the middleman is cut out and the producer is able to sell gas to the customer without cooperation of the middleman. If the middleman is needed for access to the pipeline, the value of all coalitions, except the grand coalition, is equal to zero. None of the three players alone, neither any pair of players, can create any surplus. If the access is free, the value of the coalition which consists of only producer and customer, is the same as the value of the grand coalition. The value of all other coalitions is equal to zero. One can verify that in the initial situation the Shapley value and the nucleolus allocate one-third of the total surplus to each of three players.[55] If the producer and the customer do not need the middleman to create the

[54]Hubert and Ikonnikova (2011b) consider the strategic relevance of various options to expand the network. Hubert and Cobanli (2014) investigate three pipeline projects in detail: Nord Stream, South Stream, and Nabucco. Cobanli (2014) considers pipeline projects for the Central Asian region. Hubert and Orlova (2014a) and Hubert and Orlova (2014b) look at the liberalization of pipeline access within the European Union, with the first paper emphasizing regional effects and cartels, while the second paper's focus is on customers versus local champions.

[55]The core is not unique and is given by a triangle in the three-dimensional space. Let x_i be the payoff of player $i \in \{1,2,3\}$. Normalizing the value of the grand coalition to 1, $c_1 = \{x : x_1 + x_2 + x_3 =$

surplus from trade, both the Shapley value and the nucleolus allocate zero payoff to the middleman and split the total surplus equally between the producer and the customer. By cutting out the middleman both players benefit the *equal* amount of 1/6 as compared to the first game.[56] For both games the Shapley value is equal to the nucleolus and both are located in the center of the core. One can also verify that both games are convex, guaranteeing that the Shapley value is in the core, and that the players' contributions change monotonically with the change of access rights. As these properties are lost for the more realistic models of gas networks used in the applied literature, there is little theoretical guidance regarding the properties of the different solutions.

Hubert and Orlova (2014b) study the effect of granting third party access to pipelines within EU on the balance of power between local champions, acting as middlemen, customers, and external suppliers. Under the Shapley value the customers gain less than the champions lose and one third of champions' losses leaks away to external suppliers. For the nucleolus, in contrast, Hubert and Orlova (2014b) obtain *pure redistribution* from champions to customers while outside producers gain nothing. Similarly, Hubert and Cobanli (2014) find for the Shapley value that new pipelines weaken those transit countries which they allow to circumvent, while producers and importers gain. For the nucleolus, in contrast, these pipelines appear to be essentially irrelevant. The intuition gained from our simple example is somewhat preserved for the Shapley value but it is lost for the nucleolus. Moreover, the limited empirical evidence also supports the Shapley value as the more appropriate solution for this network (Hubert and Ikonnikova (2011b), Hubert and Cobanli (2014)). While these results suggest that the Shapley value is a better guide to assess power in the gas network than the nucleolus at least two major questions remain. First, the Shapley value, if not in the core, may be an unlikely outcome because it lacks stability. Second, the nucleolus is just one element of the core and may be misleading when used to measure the impact of some change on the set of stable allocations.

In this paper we attempt to provide a more systematic evaluation of the three concepts. Using the model developed in Hubert and Orlova (2014b), we study how the

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$1, x_1 + x_2 \geq 0, x_1 + x_3 \geq 0, x_2 + x_3 \geq 0, x_1 \geq 0, x_2 \geq 0, x_3 \geq 0\}$.

[56]Now the core is given by the side of the triangle determined by zero payoff to the middleman ($i = 2$); $c_2 = \{x : x_1 + x_2 + x_3 = 1, x_1 + x_2 \geq 0, x_1 + x_3 \geq 1, x_2 + x_3 \geq 0, x_1 \geq 0, x_2 \geq 0, x_3 \geq 0\}$. From the first and the third conditions it follows that $x_2 = 0$.

Shapley value and the nucleolus relate to the core. Following Hubert and Orlova (2014b) we consider three market structures. Before the onset of reforms, in the fragmented market, regional champions control local production, LNG imports, access to both transmission and distribution systems. The first step of reform is opening of access to trunk pipes that provides *free transit* of gas within EU and creates the integrated market. In the integrated market regional champions lose control over transmission, but keep control over access to local customers. The second step of reform opens access to distribution networks that provide *access to customers* in a region and leads to the fully liberalized market. In the liberalized market champions retain control only over local production and LNG imports, but they are not needed for access to local customers.

As a first result, we establish that for none of the variants considered in Hubert and Orlova (2014b) the core is ever empty, but the Shapley value never belongs to the respective core. This result, however, does not tell us anything about the degree of instability of the Shapley value and how it depends on the market structure. In an applied analysis we need measures of stability that can be used, once an allocation is not in the core. A payoff allocation is not in the core, if there exists at least one coalition which can improve by acting on its own. Shapley and Shubik (1966) generalized the concept by introducing two famous approximate cores: 'strong' ϵ-core and 'weak' ϵ-core. For the strong ϵ-core, ϵ can be interpreted as the costs of setting up a coalition. For the 'weak' ϵ-core the costs of setting up a coalition are assumed to increase in fixed proportion to the size of the coalition. These concepts induced a number of studies on approximate cores which focus on the conditions for approximate cores to be non-empty for different classes of games (e.g. Wooders and Zame (1984), Shubik and Wooders (1983), Wooders (2008)). In this paper we also take into account that it might be more difficult to set up larger coalitions, but do it in a different manner as compared to the weak ϵ-core. We approximate the core by relaxing the strong ϵ-core concept with respect to the size of deviating coalitions. For a group of players the decision to deviate from the proposed allocation should involve not only the computation of the respective value function, but also the agreement about the rent sharing. We suggest to consider whether the allocation is stable with respect to the set of coalitions, the size of which can be limited from above. The more we restrict the size of coalitions, the larger becomes the relaxed core, as the payoff allocation has to satisfy the smaller number of conditions. We call the relaxed core the $n\epsilon$-core.

The $n\epsilon$-core enables to introduce three stability measures related to the coalition size and the costs. In general, the first metric is based on the minimal costs of establishing a coalition for a given upper bound on the size of coalitions. The second metric refers to the minimal number of players, which are necessary for setting up a coalition to veto the payoff for a given costs of establishing a coalition. The third metric is a probabilistic one. It is based on the probability of picking up a deviating coalition for the given costs and for the given upper bound on the coalition size. To analyze how the instability of the Shapley value changes with liberalization, we apply the three measures to our real life model. We find that liberalization increases the degree of instability. Opening of access to pipelines increases the minimal costs of setting up a coalition that provide the stability of the Shapley value, decreases the minimal number of players in a deviating coalition and raises the probability of selecting such a coalition if we select coalitions at random.

In contrast to the Shapley value, the nucleolus belongs to the core. To relate the nucleolus and the core, we study whether the impact of reform on the nucleolus is a good indicator of the influence on the core. As the first step, we analyze the effect of liberalization on the core. To deal with the numerous inequalities, characterizing the core, we partially describe it by computing the minimal and the maximal gains of players in the core. Then, we discuss whether the change of the nucleolus is a good indicator of the change of the core.

We find that liberalization compresses the core. The core in case of the fully liberalized market is contained in the core of the integrated market, which, in its turn, is contained in the core of the fragmented market. According to this compression, the full liberalization shrinks the range of values between the minimal and the maximal payoffs of all players in the core. The impact of full liberalization is dominated by the second step of reform for the EU champions and the customers, but by the first step for the countries outside EU and for the EU regions without champions and customers. For the champion and the customers in a region the compression of the range is of the same magnidute, but is determined by different factors. For all champions the compression is a result of the decrease of maximal gains in the core. For all customers the range decreases because the minimal gains increase.

We are interested in how the change of the nucleolus is related to the change of the core.[57] We find that in the fragmented market the nucleolus of a player tends to be

[57] Two findings about the compression of the range: i) that the total effect of reform is dominated by the second step only for the EU champions and the customers and ii) that the losses of the

centrally located, i.e. in the middle between the minimal and the maximal payoffs in the core. For each step of reform for a number of players the nucleolus and the respective midpoint shift into the same direction. However, for each step we find examples of movement into the opposite direction and cases when the nucleolus changes, but the range is not affected. Overall, it is difficult to infer the pattern of the impact on the core from the change of the nucleolus. At the same time, as the core compresses, the nucleolus becomes a more precise estimate of a point in the core in the liberalized market.

To the best of our knowledge, there are no applied studies devoted to ϵ-cores and stability issues which are calibrated with real data. The literature on approximate cores is theoretical and presents non-emptiness conditions. Also, Wooders and Zame (1987) developed conditions for the Shapley value of a large game to be in the individually rational ϵ-core. To our knowledge, our paper is a first attempt to analyze the degree of instability of the Shapley value. In addition, the paper contributes to the quantitative studies using the cooperative approach. Application of the cooperative game theory to the real world problems is mainly limited to the *voting games* (Shapley and Shubik (1954)) and the *cost allocation problems* (Shubik (1962)). While the Shapley value is the most widely used measure of voting power from the cooperative game theory (Felsenthal and Machover (2004), Montero (2005)), in the literature on the cost allocation problems various solutions are applied, including the nucleolus, the Shapley value and the core.[58] For example, in the series of papers the landing fees for Birmingham airport were computed using the Shapley value and the nucleolus. Littlechild and Owen (1973) find that the fees in the Shapley value case are larger than the actual charges for the smallest and the largest aircrafts. Littlechild (1974) receives the similar results for the nucleolus. Littlechild and Thompson (1977) find that the structure of movement fees based on the Shapley value approximates the actual structure of charges better than the set of fees given the nucleolus. Comparison of the cost allocations resulted from the different solutions with the real tariffs was also conducted by Engevall et al. (1998,

champion and the customers in a region are of the same magnitude, correspond to the results in case of nucleolus. In Hubert and Orlova (2014b) we find that in case of nucleolus the second step of reform dominates the effect of full liberalization only for the EU champions and the customers, and that full liberalization leads to pure redistribution of power between the champion and the customers in a region.

[58] See Fiestras-Janeiro et al. (2011) for a detailed review of studies, applying cooperative game theory to the cost allocation problems.

2004) and Thomas (1992). Our paper refers to the empirical studies comparing the Shapley value, the nucleolus and the core.

The paper is organized as follows. In section 3.2 we describe the concepts and introduce stability measures, in section 3.3 we compare the Shapley value, the nucleolus and the core according to the amount of power allocated to players. We study the core of the games and report the influence of liberalization on the minimal and the maximal values achievable in the core in section 3.4. In section 3.5 we relate the nucleolus and the core. In section 3.6 we relate the Shapley value and the core by studying the degree of instability of the Shapley value.

3.2 Solution Concepts

The inter-dependencies among the players in the Eurasian gas network can be represented by a game in value function form $\Gamma = (N, v)$, where N is the set of players and the value (or characteristic) function $v : 2^{|N|} \rightarrow R_+$ gives the maximal payoff, which a subset of players $S \subseteq N$, also called coalition, can achieve (Hubert and Orlova (2014b)). Such representation allows us to compare the solutions for cooperative games in value function form. We denote the set of payoff vectors $x = (x_1, x_2, ..., x_n)$ which are efficient $\Sigma_{i \in N} x_i = v(N)$ and individually rational $x_i \geq v(i)$, so called imputations, as $X(\Gamma)$. We denote the set of payoff vectors, for which only the efficiency condition holds, so called pre-imputations, as $X^*(\Gamma)$.

Shapley value

The Shapley value (Shapley (1953)) assigns a unique payoff to each player, $\phi_i, i \in N$.[59] It is based on the contribution $v(S \cup i) - v(S)$ which a player i can make to the various subgroups of other players S. The Shapley value nicely captures the intuition, that a player's payoff from cooperation, interpreted as his power in the game, should increase with his importance for other players, as measured by the value of his contributions. Formally, it is calculated as player i's weighted contribution:

$$\phi_i(v) = \sum_{S : i \notin S} P(S) \, [v(S \cup i) - v(S)] \tag{3.1}$$

where $P(S) = |S|! \, (|N| - |S| - 1)! / |N|!$ is the weight given to S. The Shapley value is the unique function satisfying the axioms of symmetry, carrier and additivity. Young

[59] This paragraph is similar to the description of the Shapley value presented in Hubert and Orlova (2014b).

(1985) proved that the Shapley value is the unique symmetric allocation featuring *strong* monotonicity: a player's share never decreases when his contributions weakly increase. However, as is well known, the Shapley value may not be 'stable' in the sense that a group of players might get less than it could insure by acting on its own. This leads us to the other major criterion for solving cooperative games - the core.

Core

Let x be a vector of payoffs, and $x(S) = \sum_{i \in S} x_i,\ \ S \subseteq N$ be the corresponding payment to a group of players S. The excess $e(x, S) = v(S) - x(S)$ measures what the group would gain by acting separately rather than accepting x. If the excess is positive for a coalition, these players could block or veto x. Intuitively, it appears difficult to achieve or maintain x as a solution, if it is easy to find groups, which could improve a lot by acting on their own. The core provides for a particularly sharp formalization of this intuition. It requires that no coalition can improve by acting separately. Formally, the core is the set of payoffs x such that there exists no coalition for which the excess is positive $c = \{x \in X(\Gamma) : e(x, S) \leq 0, \forall S \subset N\}$.

One limitation of the core is that it might be empty and if not, it is rarely unique. If the game is convex, the core is not empty (Shapley (1971)). In fact, the games considered in this paper are not convex, but the core is never empty for the analyzed games. According to the definition of the core, its characterization involves $2^{|N|} - 2$ (in our case over a million) inequalities, and hence, it is of limited practical use as such. To deal with such large set of inequalities we introduce the partial description of the core. The partial description involves finding the minimal and the maximal gains of a player in the core. In the following we refer to the interval of values between the minimum and the maximum as to the 'min-max range' of a player in the core. We compute the min-max range for all players. It is important to note that one has to be careful with the interpretation of any vector with coordinates taken from the min-max ranges. Not all such vectors will belong to the core. For example, consider the vector of payoffs equal to the maximal values for all players. Obviously, the efficiency condition is not satisfied and, hence, the vector does not lie in the core. To characterize the core in an alternative way one could think about the computation of the core-center which is behind the scope of this paper.[60]

[60]González-Díaz and Sánchez-Rodríguez (2007) defined the core-center concept for games with a non-empty core. The core-center presents "the expectation of a uniform distribution defined over the

Another limitation of the core is that any given imputation x is either in the core, hence considered stable, or not in the core, hence unstable. Stability is black or white. If the game is convex, the Shapley value lies in the core (Shapley (1971)). In general, the Shapley value does not necessarily belong to the core. We find that the Shapley value is unstable for each market structure. In an applied analysis it might be useful to have a metric which allows for different degrees of stability.

Extensions of the core

Shapley and Shubik (1966) proposed a useful generalization of the core, the so called strong ϵ-core, which requires that the gains from blocking x must not be larger than a threshold ϵ, formally $c(\epsilon) = \{x \in X^*(\Gamma) : e(x, S) \leq \epsilon, \forall S \subset N\}$. The strong ϵ-core is the set of payoffs that cannot be vetoed by any coalition if establishing a coalition entails a fixed cost of ϵ (a negative ϵ indicates a bonus). It is easy to see that any x will be in the strong ϵ-core, provided ϵ is large enough. On the other side the strong ϵ-core becomes empty if ϵ is made sufficiently small. The authors defined also the weak ϵ-core by making the costs of setting up a coalition proportional to the size of coalition. Formally, $c_w(\epsilon) = \{x \in X^*(\Gamma) : e(x, S) \leq \epsilon|S|, \forall S \subset N\}$.

Here we propose to relax the strong ϵ-core with respect to the *coalition size* n in a different way than the weak ϵ-core. We allow for fixed costs of setting up a coalition and control for the number of players in a deviating coalition. We introduce an upper bound on the size of coalitions which provides stability of an allocation.

Our approach can be motivated by the following thought experiment. Consider a game (N, v). The players have to agree on a proposed payoff x. As a first step, every single player checks whether the offer is individually acceptable. In total this requires the computation of $|N|$ values $v(\{i\})$. Next, pairs of players consider whether to object x. To do so another $|N|(|N| - 1)$ values have to be computed and, upon finding that the excess is large enough, a pair would have to agree on how to share before seriously blocking the proposal.[61] Then we move on to groups of three players, then four and so on. As we reach ever larger coalitions, not only the number of necessary computations might grow, also the complexity of organizing the group will increase. Instead of relating coalition size to these

core of the game" (see González-Díaz and Sánchez-Rodríguez (2007), p. 28.)

[61] For the game with $|N|$ players there are $|N|(|N| - 1)/2$ pairs of players, but each player in a pair has to implement the calculation so that in total $|N|(|N| - 1)$ values will be computed. For the groups of k players the total number of computations is $kc_k^{|N|}$.

cost in a particular way, we propose to account for the group size directly. Let $\mathcal{S}(n),\ 1 \leq n < |N|$ denote the set of coalitions which can be formed by permutations of at most n players: $\mathcal{S}(n) = \{S \subset N : |S| \leq n,\ S \neq \emptyset, N\}$. We define the $n\epsilon$-core as $c(n,\epsilon) = \{x \in X^*(\Gamma) : e(x,S) \leq \epsilon, \forall S \in \mathcal{S}(n)\}$. Besides the fixed cost of setting up a coalition to veto x, the $n\epsilon$-core can also account for the fact that it might be more costly to set up larger coalitions. The larger we select ϵ and the smaller we select n, the larger will be the $n\epsilon$-core. Obviously, $c(1,0)$ is equivalent to individual rationality: $x_i \geq v(\{i\}),\ i \in N$. The strong ϵ-core is $c(|N|-1,\epsilon)$ and $c(|N|-1,0)$ yields the core. For a superadditive value function the Shapley Value $\phi \in c(1,0)$. Trivially $\phi \in c(|N|-1,\infty)$.

With the $n\epsilon$-core we have two dimensions to measure the stability of a given payoff x. For a given n we can look for the minimal $\epsilon^*(x,n)$ so that $x \in c(n,\epsilon^*)$ or we can ask for the minimal $n^*(x,\epsilon)$ so that $x \in c(n^*-1,\epsilon)$. In other words, $n^*(x,\epsilon)$ denotes the minimal number of players which are necessary to veto a payoff x.

Finally, we take $c(n,\epsilon)$ as given. For a payoff vector x not in $c(n,\epsilon)$, we assess the 'degree' of instability by comparing the number of coalitions which could gain from vetoing x to the total number of coalitions formed by permutations of at most n players. Let $\hat{\mathcal{S}} = \{S : S \in \mathcal{S}(n)$ and $e(x,S) > \epsilon\}$. The larger the fraction $f(x,n,\epsilon) = |\hat{\mathcal{S}}|/|\mathcal{S}(n)|$ is, the more likely it is that we pick a coalition rejecting x if we select coalitions at random.

Nucleolus

Yet another major solution concept for the cooperative games is nucleolus (Schmeidler (1969)). Let $\theta(x)$ be the vector of excesses arranged in the non-increasing order for a payoff vector x for all possible coalitions $\mathcal{S}(|N|-1)$. The vector $\theta(x)$ is lexicographically smaller than $\theta(y)$, $\theta(x) \prec \theta(y)$, if there is an integer k such that $\theta_l(x) = \theta_l(y)$ for all $l < k$, and $\theta_k(x) < \theta_k(y)$. The notation $\theta(x) \preceq \theta(y)$ means that either $\theta(x) \prec \theta(y)$ or $\theta(x) = \theta(y)$. The nucleolus of a game Γ is the set of payoff vectors that minimize θ in the lexicographic ordering over the set of all imputations $\mu = \{x \in X(\Gamma) : \theta(x) \preceq \theta(y)$ for all $y \in X(\Gamma)\}$.[62]

The nucleolus always exists and is unique. It can be considered to be the lexicographic center of a game. Maschler et al. (1979) define the lexicographic center of a game as the set of payoff vectors obtained after the termination of the process of

[62] Maschler et al. (1979), p. 331.

minimization of the maximal excesses.[63] They prove that the lexicographic center consists of a single point and is equivalent to the nucleolus.

The merit of the nucleolus over the Shapley value is that if the core of the game is non-empty, the nucleolus always belongs to the core. In general, the location of the nucleolus in the core is not known. Maschler et al. (1979) provide an example of two games, for which the cores coincide, but the values of nucleolus differ. Only in the special case of the 'big boss' games the nucleolus is the center of the core (Muto et al. (1988)). The merit of the Shapley value is that while the Shapley concept features not only the aggregate, but also the strong monotonicity, the nucleolus does not satisfy even the property of the aggregate monotonicity (Megiddo (1974), Young (1985)). Megiddo showed that if the value of the grand coalition increases and the values of all other coalitions are not changed, then the payoffs under the nucleolus can decrease. In case of the Shapley value the payoffs for all players will increase. Another advantage of the Shapley value is that it is easy to compute once the value function is defined. Calculation of the nucleolus is much more complicated. There are number of papers on the algorithmic schemes of computation of the nucleolus which involve the solution of either one linear program (Kohlberg (1972), Owen (1974)) or a sequence of linear programs (e.g. Maschler et al. (1979), Sankaran (1991), Potters et al. (1996)).

3.3 Concepts: power allocation

In this section we study how the Shapley value, the nucleolus and the core are related to each other with respect to the power in our real world game. We use the same model as in Hubert and Orlova (2014b) and, hence, we have to compute only the minimal and the maximal gains of players in the core. Here we do not describe the games determined by the three access regimes. We refer the interested reader to Hubert and Orlova (2014b) for the definition of players, for details of the model calibration and the value function calculation. We report the results for the short-sighted scenario, when investment options are not available for a coalition, and a

[63] The lexicographic center is defined by the following procedure. First, in the set of all imputations $X^0 = X(\Gamma)$ one should find the payoff vectors X^1 that minimize the maximal excess for the set of all possible coalitions $\mathcal{S}^0 = \mathcal{S}(|N| - 1)$. Denote the minimal value as ϵ^1. Then, from the set $\mathcal{S}^0$ one should take out the coalitions whose excess is equal to the minimal value ϵ^1 for all $x \in X^1$. The new set of coalitions is denoted as $\mathcal{S}^1$. The next step is to minimize the maximal excess for the reduced set of coalitions $\mathcal{S}^1$ over X^1. The process is terminated at the step k, when the set of coalitions $\mathcal{S}^k$ becomes empty. The subset of imputations X^k, obtained on the last step, is the lexicographic center of a game.

high value of demand intercept.[64] The results are robust to changes of parameters (see Appendix C).

All results are presented in the graphs (see Figures 3.1-3.3). For each player and for all three market structures we depict the min-max range as the grey bar. All figures are given as percentage of the total surplus. We also present the nucleolus and the Shapley value as the blue elliptical disks and the red circles, respectively. Trivially, as the nucleolus belongs to the core, it lies in the min-max range.

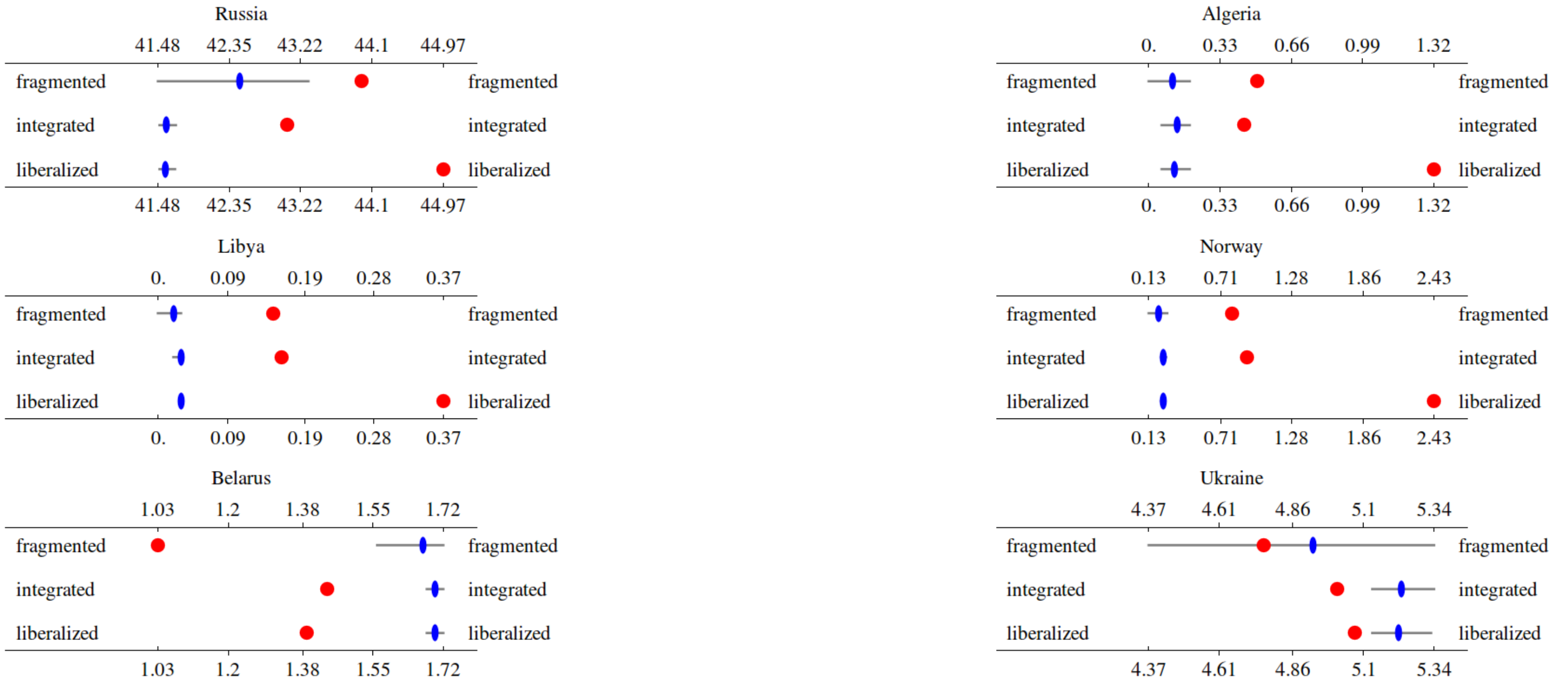
The Shapley value assigns more power to Russia, Norway, Algeria and Libya than the nucleolus (Figure 3.1). Moreover, all external producers get larger shares than the corresponding maximal values achievable in the core. Both Belarus and Ukraine have less power under the Shapley value as compared to the nucleolus. In addition, Belarus is assigned less power than the respective minimal values in the core. The same pattern holds for Ukraine in the integrated and liberalized markets. In the fragmented market the share of Ukraine under the Shapley value falls into the min-max range.

For the EU champions and the customers the results depend on the market structure (Figure 3.2). In the fragmented and integrated markets the Shapley values belong to the respective min-max ranges. The relation of the power under the Shapley value and the nucleolus depends on the player and the access regime. For example, the Shapley value assigns less power to the champions in Italy, South-West and Center-East regions, but allocates more power to Netherlands' champion than the nucleolus. The latter holds for the champion in Center region only in the fragmented market. In the liberalized market the Shapley value assigns more power to all EU champions than the nucleolus. Moreover, their shares are larger than the corresponding maximal values in the core. The opposite pattern emerges for the EU customers. They appear less powerfull under the Shapley value than under the nucleolus and receive less than their minimal values in the core.

We present the results for the EU regions without champions and customers in Figure 3.3. With few exeptions, we observe that the Shapley value allocates less power to these regions as compared to the nucleolus and that it does not belong to the min-max range.

[64]These are the basic parameter settings in Hubert and Orlova (2014b).

Figure 3.1: Different solutions for external producers and transit countries



The grey bar presents the min-max range of a player in the core. Blue elliptical disks and red circles present the nucleolus and the Shapley values, respectively. All figures are in percentage of the total surplus.

Figure 3.2: Different solutions for EU champions and customers

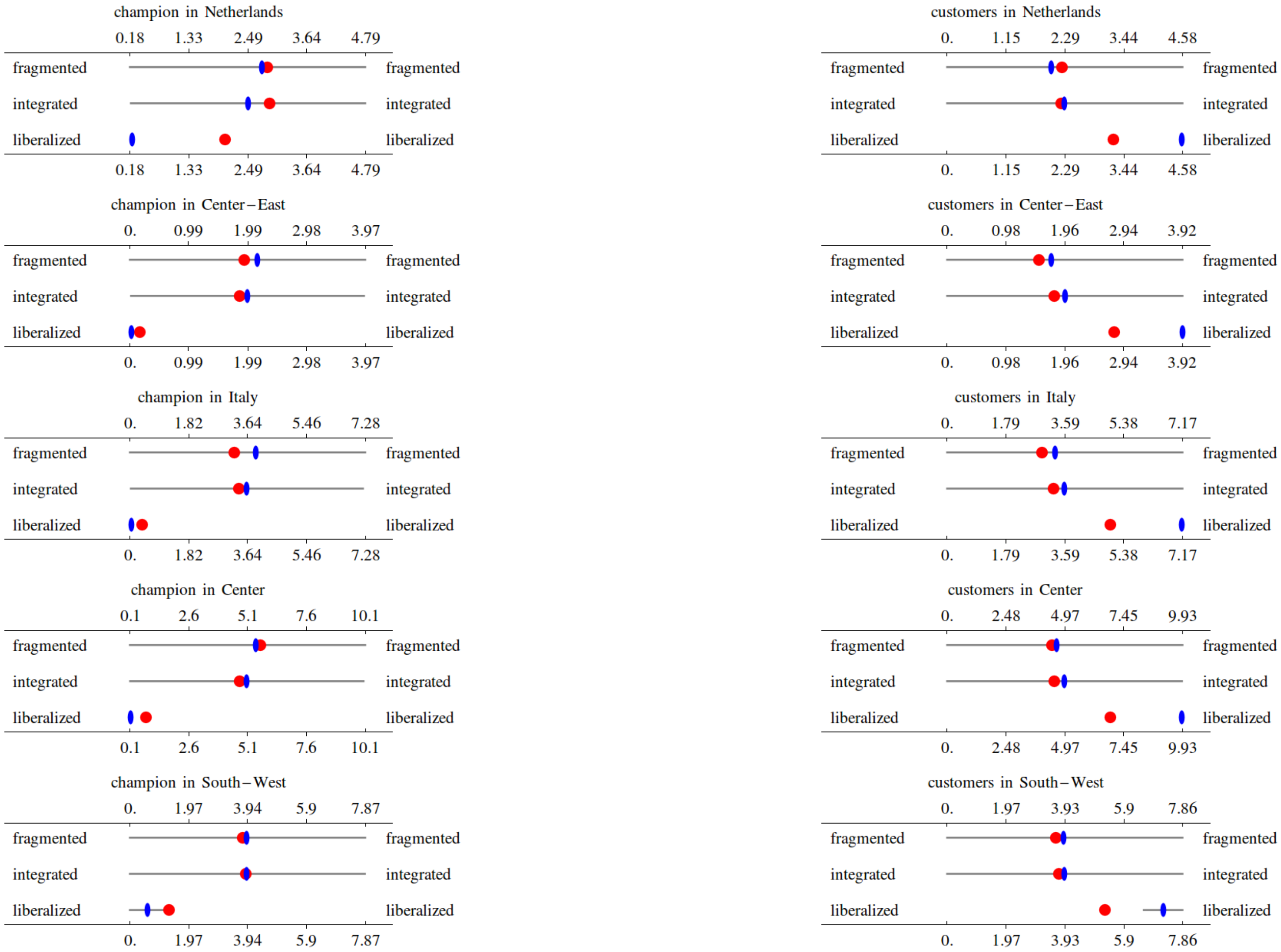
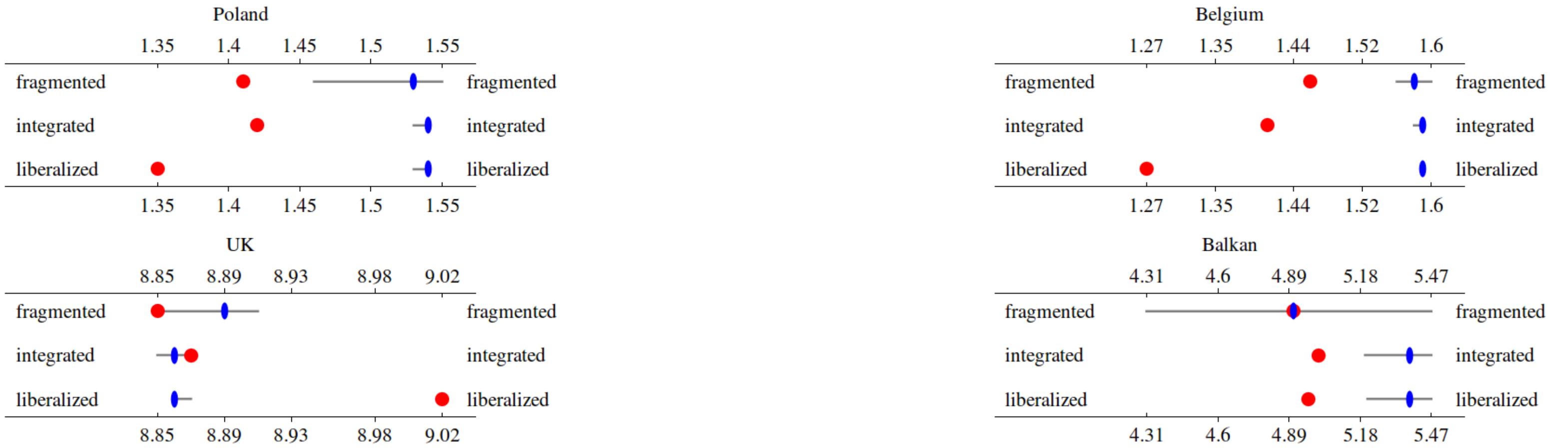


Figure 3.3: Different solutions for EU regions



3.4 Compression of the Core

As it can be seen from Figures 3.1-3.3, liberalization compresses the min-max range for all players. If the compression results in a small scope between the minimal and the maximal values, then we will not find the allocation in the core which is very different from the nucleolus. To understand why we observe the compression of the core, we prove the simple lemma.

Consider two games $\Gamma^0 = (N, v^0)$ and $\Gamma^1 = (N, v^1)$ with non-empty cores. Let games Γ^0 and Γ^1 have the same set of players and the same values of grand coalition: $v^0(N) = v^1(N)$ (as well as the same values of the empty set: $v^0(\emptyset) = v^1(\emptyset) = 0$). For other coalitions the value function of Γ^1 either increases or does not change in comparison to the value function of Γ^0: $v^1(S) \geq v^0(S)\ \forall S \neq N$. We denote the core for the game Γ^0 as c^0 and for the game Γ^1 as c^1.

Lemma 1: If $v^0(N) = v^1(N)$ and $v^1(S) \geq v^0(S)\ \forall S \neq N$, then $c^1 \subseteq c^0$.

Proof: Recall from the definition of the core (section 3.2) that the core for Γ^0 is defined as:

$$c^0 = \{x : \begin{cases} \sum_{i \in S} x_i \geq v^0(S) & \forall S \neq \emptyset, N, \\ \sum_{i=1}^{N} x_i = v^0(N) \end{cases} \} \tag{3.2}$$

The core for Γ^1 is defined as:

$$c^1 = \{x : \begin{cases} \sum_{i \in S} x_i \geq v^1(S) & \forall S \neq \emptyset, N, \\ \sum_{i=1}^{N} x_i = v^1(N) \end{cases} \} \tag{3.3}$$

As the values of grand coalition are equal $v^1(N) = v^0(N)$ for two games, we can rewrite (3.3) in the following form:

$$c^1 = \{x : \begin{cases} \sum_{i \in S} x_i \geq v^1(S) & \forall S \neq \emptyset, N, \\ \sum_{i=1}^{N} x_i = v^0(N) \end{cases} \} \tag{3.4}$$

Clearly, as $v^1(S) \geq v^0(S)\ \forall S \neq N$, $c^1 \subseteq c^0$. □

Consecutive liberalization of access to the transmission and distribution systems does not change the total surplus due to calibration (Hubert and Orlova (2014b)), but either increases the value function or does not change the value function for any other coalition: $v^2(S) \geq v^1(S) \geq v^o(S)\ \forall S \neq N$. In other words, the value function never decreases for any coalition. We know, that the core is not empty for each market structure. Then, by Lemma 1, the core compresses with each step of liberalization. The core in the fragmented market case contains the core in the integrated market case, and the latter contains the core in the fully liberalized market case. Compression of the core is reflected in the change of minimal and maximal values that players get in the core.

Typically, it is difficult to explain why the minimal and the maximal values change. But occasionally the effect is simple. The maximal value of a player in the core might be given by his contribution to the grand coalition. The player cannot require a higher payment, as then the rest of the players will 'kick' him out and form the coalition on their own. If for either two market structures the maximum of a player is equal to the respective contribution, it is enough to consider the effect of reform on the contribution. The minimal value of a player in the core, in the simplest case, is given by his stand alone value. In other words, by the amount that the player can assure on his own. Liberalization does not influence the stand alone values of players. If for either two market structures the minimum of a player is equal to his stand alone value, then trivially there is no effect on the minimum. If the minimum of a player is determined by the binding individual rationality constraint only for the initial market structure, we proceed as following. For the new access regime we find the coalitions corresponding to the binding constraints. Then we consider the effect of reform on the values of such coalitions.

We study the effect of each step of reform and the overall impact of full liberalization on the minimal value, the maximal value and the difference between the two. We refer to the difference between the maximal and the minimal values as to the range or the span. Results are presented in Table 3.1. All figures are expressed as percentage of the redistributed amount resulted from the full liberalization.[65] In the columns 2-4 we report the influence of liberalization of access to the high-pressure pipelines on all three values. In the columns 5-7 we report the incremental effect of liberalization of access to the distribution systems. In the columns 8-10 the impact of full liberalization is shown. The range can be reduced either because of the

[65] The redistributed amount from the full liberalization is equal to the sum of benefits of those players who gain from two steps of reform. For the estimates of redistribution given nucleolus see Hubert and Orlova (2014b).

Table 3.1: Impact of Liberalization on the Minimal/Maximal Values in the Core

	Change of Minimal/Maximal Values in the Core [% of Redistribution]								
	step 1: transmission			step 2: distribution			two steps together		
	Δmin	Δmax	Δspan	Δmin	Δmax	Δspan	Δmin	Δmax	Δspan
Outside Countries									
Russia	0.1	−8.9	−9.0	0.0	−0.1	−0.1	0.1	−9.0	−9.1
Belarus	0.6	0.0	−0.6	0.0	0.0	0.0	0.6	0.0	−0.6
Ukraine	4.2	0.0	−4.2	0.0	0.0	0.0	4.2	−0.1	−4.2
Algeria	0.3	0.0	−0.3	0.0	0.0	0.0	0.3	0.0	−0.3
Libya	0.1	0.0	−0.1	0.0	0.0	0.0	0.1	0.0	−0.1
Norway	0.5	0.0	−0.6	0.0	0.0	0.0	0.5	−0.1	−0.6
Netherlands									
champion	0.1	0.0	−0.1	0.0	−25.2	−25.2	0.2	−25.2	−25.4
customers	0.0	0.0	0.0	25.2	0.0	−25.2	25.2	0.0	−25.2
Center-East [a]									
champion	0.1	−0.1	−0.2	0.0	−21.7	−21.7	0.1	−21.8	−21.9
customers	0.0	0.0	0.0	21.6	0.0	−21.6	21.6	0.0	−21.6
Italy									
champion	0.2	−0.4	−0.6	0.0	−39.6	−39.6	0.2	−40.0	−40.2
customers	0.0	0.0	0.0	39.4	0.0	−39.4	39.4	0.0	−39.4
Center [b]									
champion	0.1	−0.4	−0.4	0.0	−54.8	−54.8	0.1	−55.2	−55.3
customers	0.0	−0.1	−0.1	54.6	0.0	−54.6	54.6	−0.1	−54.7
South-West [c]									
champion	0.0	0.0	0.0	0.0	−37.0	−37.0	0.0	−37.0	−37.0
customers	0.0	0.0	0.0	36.3	0.0	−36.3	36.3	0.0	−36.3
Poland	0.4	0.0	−0.4	0.0	0.0	0.0	0.4	0.0	−0.4
Belgium	0.1	0.0	−0.2	0.0	0.0	0.0	0.2	0.0	−0.2
United Kingdom	0.0	−0.2	−0.3	0.0	0.0	0.0	0.0	−0.2	−0.3
Turkey & Balkan[d]	4.9	0.0	−4.9	0.0	0.0	0.0	5.0	0.0	−5.0

[a] Austria, Czech Republic, Slovakia, Hungary, Serbia and Slovenia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

increase of minimal value or the decrease of maximal value, or because of both changes. We report the impact on the minimal and the maximal values and point out the change, which is the most important for the compression.

We start analysis with the first step of liberalization. For all EU champions, except the champion in South-West, we observe a modest compression. The decrease of maximal values tends to be more significant than the increase of minimal values.[66] In the fragmented market for all champions the maximal payoffs are determined by the respective contributions to the grand coalition. The pattern is similar in the integrated market.[67] Consequently, we may consider the effect of the first step on the contributions. Opening of access to trunk pipes decreases contributions of champions to the grand coalition as in the integrated market the gas can be shipped freely within EU.[68]

For the EU customers, except the customers in Center, there is no compression of the range. In the fragmented and integrated markets for all customers the minimal values are determined by the respective stand alone values. As a result, we do not observe any impact on the minimal values. The maximal values of all customers, except the customers in Center, are determined by the corresponding contributions to the grand coalition.[69] Neither step of reform has impact on the contribution of a customer to the grand coalition. As a result, we observe the minor decrease of the range only for the customers in Center.

The span compresses for the producers and the transit countries outside EU. For all countries, except Russia, the range decreases due to the increase of minimal values. Only for North-African countries the increase of minimal values corresponds to the simple case. In the fragmented market the minimal values of Algeria and Libya are determined by the respective stand alone values. In the integrated market producers can ship gas freely within EU and the minimal values are determined by the coalitions with regions which could not be accessed in the fragmented market. Opening of access to trunk pipes increases the values of such coalitions making the individual rationality constraints non-binding. For Russia the compression is the strongest, but the decrease of maximal value cannot be explained by the simple case. For other producers and transit countries the maximal values are either determined by the respective contributions or are slightly less than the contributions. Neither step of reform has impact on the contribution of a supplier or a transit

[66] The only exception is the champion in Netherlands, for the champion in Center-East the two effects are shown as equal due to rounding.

[67] In the integrated market only for the champion in Center the calculated maximal value is less than the respective contribution. But the difference between the respective contribution and the maximum is minor.

[68] The contribution of the champion in Netherlands is not affected by the first step of reform.

[69] Only in the integrated market for the customers in Center the calculated maximal value is slightly less than the respective contribution.

country. As a result, if the maximal values are affected, they decrease only slightly.

The incremental impact of liberalization of access to the distribution systems on *the range* varies for the different groups of players. For all EU champions and customers the span decreases. The compression resulted from the second step of reform is much larger than from the first step. Therefore, the total impact on the range is clearly dominated by the second step for the champions and the customers. The pattern is different for all other players. The incremental compression is either zero or close to zero, and hence, tends to be substantially less than from the opening of access to high-pressure pipelines. Therefore, the total effect is dominated by the first step of reform for these players. In the following we find the main factors of compression for the EU champions and the customers.

For all champions the impact of the second step of reform on the minimal values is essentially zero. The maximal values drop substantially. Recall, that in the integrated market the maximal values tend to be determined by the respective contributions to the grand coalition. In the liberalized market this pattern holds for all champions. In contrast to the integrated market, in the liberalized market customers can be reached without a champion. Hence, the share of the total surplus which the champion can require decreases substantially. As a result, for the EU champions the compression from the full liberalization is determined by the decrease of maximal values from the opening of access to distribution networks.

The pattern is reversed for the EU customers. The impact on the maximal values is essentially zero, but the minimal values increase a lot. In the integrated market the minimal values are determined by the respective stand alone values. In the liberalized market the individual rationality constraints become non-binding. The minimal values increase because opening of access to distribution networks raises the values of coalitions with customers which could not be accessed by producers in the integrated market. As a result, for the EU customers the compression from the full liberalization is determined by the increase of minimal values from the opening of access to low-pressure pipelines.

We report the results for the last column of Table 3.1. The range compresses significantly for the EU champions and the customers. Though we observe the different factors of compression, the magnitude of the loss in the span is approximately the same for the champion and the customers in a region. For example, for the champion in Netherlands the range decreases by 25.4 percentage points. The decrease for the customers is equal to 25.2 percentage points. In comparison to the champions and the customers, the magnitude of losses in the span is low for all other players. The largest compression is observed for Russia and is equal to 9.1 percentage points. It is more than two times less than the lowest shrinkage within the group of EU champions and customers.[70]

3.5 The Nucleolus and the Core

In Hubert and Orlova (2014b) we find that under the nucleolus the total effect of reform on power is dominated by the second step only for the EU champions and the customers. For all other players the total effect is dominated by the first step of reform. We receive the similar result for the compression of the core. In addition, given the nucleolus, there is pure redistribution of power between the champion and the customers in a region. We find that the min-max range compresses for both the champion and the customers in a region and the losses in the range are of the same magnitude. At a first glance, these findings allow us to assume that the change of the nucleolus is a good indicator of the impact of liberalization on the core.

To check this hypothesis, for each player we consider the direction of the movement of the nucleolus as compared to the shift of the midpoint of the min-max range. The idea behind such measurement is the following. On the one hand, in the fragmented market for most of the players the nucleolus is centrally located in the min-max range (see Figures 3.1-3.3).[71] On the other hand, the movement of the midpoint depicts the pattern of compression of the min-max range. If the increase of minimal value is larger than the decrease of maximal value, then the center shifts to the right. If the opposite holds, then the center shifts to the left. In the previous section we discussed the dominant effects of compression. Thus, we consider the impact of reform on the nucleolus to be a good indicator of the effect on the core, if the nucleolus is shifted into the same direction as the midpoint of the respective min-max range.

We start analysis with the first step of reform. The nucleolus and the respective center move into the same direction for two-third of the players. This pattern holds

[70]The lowest compression of the span within the group of EU champions and customers is equal to 21.6 percentage points and corresponds to the customers in Center-East region.

[71]The difference between the center and the nucleolus is larger than 10% only for Belarus, Belgium, Poland and UK. For these players the nucleolus is shifted to the right endpoint of the min-max range.

for all players in the group of outside producers and transit countries and for all players in the group of EU regions without champions and customers (see Figures 3.1 and 3.3). Within the group of EU champions and customers the values shift into the same direction only for the champions in Center, Center-East and Italy. In some cases the compression 'forces' the nucleolus to move into the same direction. Consider, for example, Russia. The decrease of maximum is larger than the increase of minimum so that the midpoint shifts to the left. The nucleolus moves into the same direction. As the maximal value in the integrated market is less than the nucleolus in the fragmented market, the movement into the opposite direction is not possible. For the rest of the players we observe two cases. First, the nucleolus shifts into the opposite direction as compared to the respective midpoint. Second, the midpoint is not affected, but the nucleolus changes. The first case holds for the champions in Netherlands and South-West and for the customers in Center. The second case holds for all other customers.

These two cases are also fulfilled for the second step of reform. The nucleolus moves into the opposite direction for Algeria. For Belarus the min-max range is not affected, but the nuclelous decreases. For all other players the values shift into the same direction. The champions and the customers are exposed to the largest shift of both the nucleolus and the center. In contrast to the integrated market, in the liberalized market for the champions and the customers the nucleolus is not always centrally located in the respective min-max range. Nevertheless, the magnitude of the shift of the nucleolus and the midpoint is approximately the same due to the substantial compression of the min-max range. In other words, the nucleolus becomes a more precise estimate of a point in the core in the liberalized market.

Overall, in the fully liberalized market, as compared to the fragmented market, for all players the nucleolus and the midpoint move into the same direction. But for each step of reform we find exceptions. We find players, for which the values shift into the opposite direction as well as cases when the midpoint is not affected, but the nucleolus changes. Taken together, not always the impact of reform on the nucleolus corresponds well to the effect on the core.

3.6 Stability: the Shapley value and the Core

For each access regime there are a number of coalitions which find it profitable to deviate from the Shapley value. This means that for neither market structure the Shapley value is in the core and, hence for neither market structure the Shapley

Table 3.2: Impact of Liberalization on Stabiltiy Measures

	Stability measures		
	fragmented	integrated	liberalized
$\epsilon^*(\phi, \lvert N\rvert - 1)/\sum \phi^0_{EU}$	1.7	2.2	8.0
$n^*(\phi, 0) - 1$	8	1	1
$f(\phi, \lvert N\rvert - 1, 0)$	0.0002	0.0019	0.0907

value is stable. In this section we study the degree of instability of the Shapley value depending on the access regime. To implement this analysis we relate the Shapley values to the measures of stability introduced in Section 3.2. The results for the three metrics are presented in Table 3.2. The first metric to consider is the minimal costs of setting up a coalition of any size $\epsilon^*(\phi, |N| - 1)$, such that it is not profitable to deviate from the Shapley value. We report $\epsilon^*(\phi, |N| - 1)$ as percentage of the joint share of EU players in the fragmented market in the first row of Table 3.2. In the second row, for zero costs of establishing a coalition, we present the second metric. The second measure is the maximal number of players $n^*(\phi, 0) - 1$, such that all coalitions, formed by permutations of at most this number, cannot block the Shapley value. In the third row we find $f(\phi, |N| - 1, 0)$, the fraction of coalitions which could gain from vetoing the Shapley value. Computation of the third metric involves assumption that setting up a coalition of any size would not cost anything.

We start analysis with the first metric. In the fragmented market the costs of establishing a coalition have to constitute at least 1.7% of the joint rent of the EU players. Then rejection of the Shapley value becomes unprofitable for all coalitions. Opening of access to trunk pipes raises the value of threshold up to 2.2%. In the liberalized market the costs increase up to 8%, which is several times larger than the corresponding values in both the fragmented and integrated markets. With liberalization a coalition gets access to resources that were unavailable in the fragmented market and, hence, can gain more than before the reform. As a result, the costs of establishing a coalition have to increase in order to make the deviation from the respective Shapley value unprofitable.

Now we turn to the second metric, related to the size of deviating coalitions. In the following calculations we set ϵ equal to zero. For each market structure we search for $n^*(\phi, 0)$, the minimal number of players necessary for setting up a coalition to veto the corresponding Shapley value. In the fragmented market $n^*(\phi, 0) = 9$, so that the coalitions, formed by permutations of at most 8 players, cannot improve by acting on their own. In other words, in the fragmented market almost half of the players has to be in a coalition to be able to veto the Shapley value. We find two coalitions with 9 players for which the excess is positive. The two coalitions include different types of players: EU champions and customers, outside producers, transit countries for Russian gas and Turkey & Balkan region.[72] In the integrated and liberalized markets the size of deviating coalitions diminishes. In both cases the minimal number of players in a deviating coalition is equal to 2. In the integrated market Belgium and Libya find it more profitable to cooperate on their own rather than to accept their Shapley values. In the liberalized market the customers in Center region can veto the Shapley value together with either the champion in Netherlands or with Norway. Thus, while in the fragmented market the deviation requires bargaining between relatively large sets of players, in the integrated/liberalized market the deviation from the Shapley value can be profitable even when there are only two players in a coalition.

The third metric is the fraction of coalitions, which could block the Shapley value. In the following calculations we set ϵ equal to zero and consider the set of coalitions which can be formed by permutations of at most 19 players ($n = |N| - 1 = 19$). We find the ratio of the number of coalitions which can veto the Shapley value and the total number of coalitions. The fraction of deviating coalitions increases when we move from the fragmented to the integrated and liberalized markets. In the fragmented market, the fraction is the lowest and is close to zero. In the integrated market, the share increases, but it is still less than 1% of the total number of relevant coalitions. The fraction increases further in the liberalized market, so that with probability 9% we can pick a coalition rejecting the Shapley value if we select coalitions at random.

Therefore, as liberalization provides access to new resources for a coalition, the attractiveness to act on its own increases in the integrated/liberalized market in comparison to the fragmented market. As a result, the instability of the Shapley value raises with liberalization with respect to all three measures. For the two measures, the costs of establishing a coalition and the fraction of deviating coalitions, the second step of reform dominates the first step with respect to the increase of

[72]The coalitions are: $\{$ Algeria, Turkey & Balkan, Belarus, customers in Center-East, champion in Center-East, customers in Italy, champion in Italy, Russia, Ukraine $\}$ and $\{$ Turkey & Balkan, Belarus, customers in Center-East, champion in Center-East, customers in Italy, champion in Italy, Libya, Russia, Ukraine $\}$.

the degree of instability. The opposite holds for the second criteria.

3.7 Conclusion

When applying cooperative game theory to the real world problems, we have to decide on how to solve the game. Though in the simple models different solutions may provide the same results, it can be completely misleading for the more complicated cases. We show that liberalization of access in simple system leads to the same power redistribution in case of the Shapley value and the nucleolus. Cutting out the middleman benefits both producer and customer. In Hubert and Orlova (2014b) we consider the Eurasian natural gas supply system and study the impact of opening access to transmission and distribution networks on the balance of power between regional champions, customers and external producers. In this case the Shapley value and the nucleolus yielded different results with respect to the power redistribution.

In general, the choice of the concept is complicated by the fact that the Shapley value and the nucleolus have different merits and shortcomings. The nucleolus presents the stable imputation for the game with the non-empty core, which is not necessarily true for the Shapley value. The Shapley value is a monotone concept, but the nucleolus is not.

In this paper we use the model of the Eurasian natural gas supply system to relate the Shapley value and the nucleolus to the core. We examine the degree of instability of the Shapley value and how it depends on the market structure. We study whether the effect of liberalization on the nucleolus is a good indicator of the influence on the core.

To evaluate the degree of instability of a payoff allocation which is not in the core, we propose several stability measures. We relax the strong ϵ-core concept by taking into account the size of deviating coalitions. Using the $n\epsilon$-core one can study whether the payoff allocation is stable with respect to the set of coalitions, the size of which is bounded from above. We introduce three stability measures related to the coalition size and the costs of setting up a coalition. We find that liberalization increases the instability of the Shapley value for all criteria.

To study whether the change of the nucleolus might be considered as an indicator of the change of the core in our model, we first analyze the impact of liberalization on the core. We find that liberalization consecutively compresses the core.

The compression is depicted in the decrease of the range of values between the minimum and the maximum of a player in the core. As the nucleolus tends to be centrally located in the min-max range in the fragmented market, we compare the direction of the shift of the nucleolus with the movement of the respective midpoint. For each step of reform we find players characterized by the movement of values into the opposite direction. In addition, we also find examples when the min-max range is not affected, but the nucleolus changes. Hence, it is difficult to judge about the change of the core on the basis of the impact of liberalization on the nucleolus.

Taken together, the Shapley value suits better for the application to the Eurasian natural gas system. As it is pointed out in Hubert and Orlova (2014b), the results under the Shapley value correspond to the intuition derived from the middleman story. Though the instability of the Shapley value increases for all criteria, the degree of increase differs between the metrics. The first measure, the minimal costs, and the third measure, the fraction of deviating coalitions, provide less sharp results than the second measure. Liberalization consecutevily increases the minimal costs of establishing a coalition, but even in the fully liberalized market this amount does not exceed 10% of the joint rent of EU players. The fraction of deviating coalitions in the liberalized market never exceeds 20%. Simultaneously, according to the second metric, only two players are enough to reject the Shapley value in the fully liberalized market. Looking at all three metrics together, we find it easier to apply the Shapley value in the fragmented market. So that taking into account the second criteria, application of the Shapley value in the integrated and liberalized markets requires more caution.

Appendix C

C.1 Robustness

As in Hubert and Orlova (2014b), we assess the robustness of our results by considering three more variants: a high value of demand intercept and the far-sighted scenario, a low value of intercept and the short-sighted scenario, the low value of intercept and the far-sighted scenario. We will discuss the robustness of our results in the same order as they are reported in the main text.

Power allocation

We start analysis with the comparison of concepts according to the power allocation (see Figures C.1-C.9). With minor modifications, all previous statements from the main text could be repeated for each of three scenarios. For example, for all variants of parameters it holds that the Shapley value assigns more power to all outside producers than the nucleolus and the core. It also holds that Belarus and Ukraine have less power in the Shapley value case as compared to the nucleolus. Moreover, for Belarus the shares are less than the respective minimal values in the core. Only for Ukraine it depends on the scenario and the access regime whether the Shapley value falls into the min-max range.

For all scenarios, in the fragmented and integrated markets, the Shapley values of champions and customers belong to the respective min-max ranges. All results for the liberalized market can be repeated. For all scenarios the Shapley value assigns more power to all champions than the nucleolus and the core. All customers have less power under the Shapley value than under the nucleolus and the core.

In case of all variants the Shapley value tends to allocate less power to other EU regions as compared to the nucleolus. For the low value of demand intercept only in half of the cases it holds that the Shapley value does not belong to the respective min-max range.

Compression of the core.

The impact of liberalization on the minimal values, the maximal values and the range is presented in Tables C.1-C.3. For all scenarios it holds that the total effect on the range is dominated by the second step of reform only for the EU champions and the customers, but by the first step of reform for all other players. For the champions the compression of the range is determined by the decrease of maximal values resulted from the second step of reform. For the customers the compression is determined by the increase of minimal values from the second step. The statements concerning the influence of liberalization on the minimum and the maximum hold for all scenarios.[73] For example, in the fragmented and integrated markets the minimal values of all customers are determined by the binding individual rationality constraints so that we do not observe any impact of the first step of reform on the minimal values of customers. In contrast, in the liberalized market the individual rationality constraints become non-binding. In other words, the minimal values increase with the second step of reform.

The nucleolus and the core.

The main results concerning the relation of the nucleolus and the core are robust to changes of parameters. With the first step of reform the nucleolus and the respective midpoint move into the same direction for 60% or 70% of the players, depending on the variant. Within the group of champions and customers such pattern holds only for two or four players. For other players in this group the values shift into the opposite direction or the min-max range is not affected, but the nucleolus changes. For the players outside EU and for the EU regions without champions and customers the values shift into the same direction for all scenarios. In case of the second step of reform for all variants it holds that for all champions and customers the nucleolus is forced to move into the same direction as the respective midpoint. Among other players we find examples when the values shift into the opposite direction. We also find cases when the min-max range is not affected, but

[73]Minor modifications in the statements might refer to the maximal values. In the basic scenario for a number of maximal values it holds that the value is equal to the respective contribution. With the change of parameters some of these maximal values become slightly less than the respective contributions.

the nucleolus changes.

Stability: the Shapley value and the core.

Results concerning the degree of instability of the Shapley value are robust to changes of parameters (Tables C.4-C.6). For all scenarios it holds that liberalization increases the instability of the Shapley value. The minimal costs of establishing a coalition in the fully liberalized market are several times larger than the counterparts in the fragmented and integrated markets. Opening of access to pipelines decreases the minimal number of players in a deviating coalition. In the fully liberalized market only two players are enough to veto the Shapley value. The fraction of deviating coalitions raises with each step of reform. The increase realized from the second step of liberalization is larger than from the first step for all scenarios.

Table C.1: Impact of Liberalization on the Minimal/Maximal Values in the Core (far-sighted scenario, high intercept)

	Change of Minimal/Maximal Values in the Core [% of Redistribution]								
	step 1: transmission			step 2: distribution			two steps together		
	Δmin	Δmax	Δspan	Δmin	Δmax	Δspan	Δmin	Δmax	Δspan
Outside Countries									
Russia	0.1	−6.7	−6.7	0.0	−0.1	−0.1	0.1	−6.7	−6.8
Belarus	0.6	0.0	−0.6	0.0	0.0	0.0	0.6	0.0	−0.6
Ukraine	1.3	0.0	−1.3	0.0	0.0	0.0	1.3	−0.1	−1.4
Algeria	0.3	0.0	−0.3	0.0	0.0	0.0	0.3	0.0	−0.3
Libya	0.1	0.0	−0.1	0.0	0.0	0.0	0.1	0.0	−0.1
Norway	0.5	0.0	−0.6	0.0	0.0	0.0	0.5	−0.1	−0.6
Netherlands									
champion	0.1	0.0	−0.1	0.0	−25.8	−25.8	0.2	−25.8	−25.9
customers	0.0	0.0	0.0	25.8	0.0	−25.8	25.8	0.0	−25.8
Center-East [a]									
champion	0.1	−0.1	−0.2	0.0	−22.2	−22.2	0.1	−22.3	−22.4
customers	0.0	0.0	0.0	22.1	0.0	−22.1	22.1	0.0	−22.1
Italy									
champion	0.2	−0.4	−0.6	0.0	−40.5	−40.6	0.2	−41.0	−41.2
customers	0.0	0.0	0.0	40.3	0.0	−40.3	40.3	0.0	−40.3
Center [b]									
champion	0.1	−0.4	−0.5	0.0	−56.1	−56.1	0.1	−56.5	−56.5
customers	0.0	−0.1	−0.1	55.9	0.0	−55.9	55.9	−0.1	−56.0
South-West [c]									
champion	0.0	0.0	0.0	0.0	−44.1	−44.1	0.0	−44.1	−44.1
customers	0.0	0.0	0.0	43.7	0.0	−43.8	43.7	0.0	−43.8
Poland	0.4	0.0	−0.4	0.0	0.0	0.0	0.4	0.0	−0.4
Belgium	0.1	0.0	−0.2	0.0	0.0	0.0	0.2	0.0	−0.2
United Kingdom	0.0	−0.2	−0.3	0.0	0.0	0.0	0.0	−0.2	−0.3
Turkey & Balkan[d]	3.8	0.0	−3.8	0.0	0.0	0.0	3.9	0.0	−3.9

[a] Austria, Czech Republic, Slovakia, Hungary, Serbia and Slovenia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

Table C.2: Impact of Liberalization on the Minimal/Maximal Values in the Core (short-sighted scenario, low intercept)

	Change of Minimal/Maximal Values in the Core [% of Redistribution]								
	step 1: transmission			step 2: distribution			two steps together		
	Δmin	Δmax	Δspan	Δmin	Δmax	Δspan	Δmin	Δmax	Δspan
Outside Countries									
Russia	0.1	−8.8	−9.0	0.0	−0.2	−0.2	0.1	−9.0	−9.1
Belarus	1.3	0.0	−1.3	0.0	0.0	0.0	1.3	0.0	−1.3
Ukraine	4.5	−0.1	−4.6	0.1	0.0	−0.1	4.6	−0.1	−4.7
Algeria	1.0	0.0	−1.0	0.0	0.0	0.0	1.0	0.0	−1.0
Libya	0.3	0.0	−0.3	0.1	0.0	−0.1	0.4	0.0	−0.4
Norway	1.6	−0.1	−1.7	0.0	0.0	0.0	1.6	−0.1	−1.7
Netherlands									
champion	0.5	0.0	−0.5	0.0	−25.4	−25.5	0.5	−25.4	−25.9
customers	0.0	0.0	0.0	25.3	0.0	−25.3	25.3	0.0	−25.3
Center-East [a]									
champion	0.3	−0.2	−0.5	0.0	−22.1	−22.1	0.3	−22.3	−22.6
customers	0.0	0.0	0.0	21.7	0.0	−21.7	21.7	0.0	−21.7
Italy									
champion	0.5	−1.3	−1.8	0.1	−40.3	−40.4	0.6	−41.6	−42.2
customers	0.0	0.0	0.0	39.6	0.0	−39.6	39.6	0.0	−39.6
Center [b]									
champion	0.2	−1.2	−1.4	0.0	−55.7	−55.7	0.2	−56.9	−57.1
customers	0.0	−0.3	−0.3	55.1	0.0	−55.2	55.1	−0.3	−55.4
South-West [c]									
champion	0.0	−0.1	−0.1	0.0	−37.8	−37.9	0.0	−38.0	−38.0
customers	0.0	0.0	0.0	36.7	0.0	−36.8	36.7	−0.1	−36.8
Poland	0.9	−0.2	−1.1	0.1	0.0	−0.1	1.0	−0.2	−1.1
Belgium	0.5	−0.1	−0.6	0.0	0.0	0.0	0.5	−0.1	−0.6
United Kingdom	0.1	−0.7	−0.8	0.0	0.0	0.0	0.1	−0.7	−0.8
Turkey & Balkan[d]	3.4	0.0	−3.4	0.2	0.0	−0.2	3.6	0.0	−3.6

[a] Austria, Czech Republic, Slovakia, Hungary, Serbia and Slovenia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

Table C.3: Impact of Liberalization on the Minimal/Maximal Values in the Core (far-sighted scenario, low intercept)

	Change of Minimal/Maximal Values in the Core [% of Redistribution]								
	step 1: transmission			step 2: distribution			two steps together		
	Δmin / Δmax / Δspan			Δmin / Δmax / Δspan			Δmin / Δmax / Δspan		
Outside Countries									
Russia	0.1	−8.4	−8.5	0.0	−0.2	−0.2	0.1	−8.5	−8.7
Belarus	1.4	0.0	−1.4	0.0	0.0	0.0	1.4	0.0	−1.4
Ukraine	2.2	−0.1	−2.3	0.1	0.0	−0.1	2.3	−0.1	−2.4
Algeria	1.0	0.0	−1.0	0.0	0.0	0.0	1.0	0.0	−1.0
Libya	0.3	0.0	−0.3	0.1	0.0	−0.1	0.5	0.0	−0.5
Norway	1.6	−0.1	−1.7	0.0	0.0	0.0	1.6	−0.1	−1.7
Netherlands									
champion	0.5	0.0	−0.5	0.0	−26.0	−26.0	0.5	−26.0	−26.5
customers	0.0	0.0	0.0	25.9	0.0	−25.9	25.9	0.0	−25.9
Center-East [a]									
champion	0.3	−0.2	−0.5	0.0	−22.6	−22.6	0.3	−22.8	−23.1
customers	0.0	0.0	0.0	22.1	0.0	−22.1	22.1	0.0	−22.1
Italy									
champion	0.5	−1.3	−1.9	0.1	−41.2	−41.3	0.6	−42.5	−43.2
customers	0.0	0.0	0.0	40.4	0.0	−40.5	40.4	0.0	−40.5
Center [b]									
champion	0.2	−1.3	−1.5	0.0	−56.9	−56.9	0.2	−58.2	−58.4
customers	0.0	−0.3	−0.3	56.3	0.0	−56.4	56.3	−0.3	−56.6
South-West [c]									
champion	0.0	−0.1	−0.1	0.0	−44.3	−44.3	0.0	−44.4	−44.4
customers	0.0	0.0	0.0	43.3	0.0	−43.3	43.3	−0.1	−43.3
Poland	0.9	−0.2	−1.1	0.1	0.0	−0.1	1.0	−0.2	−1.1
Belgium	0.5	−0.1	−0.6	0.0	0.0	0.0	0.5	−0.1	−0.6
United Kingdom	0.1	−0.7	−0.8	0.0	0.0	0.0	0.1	−0.7	−0.8
Turkey & Balkan [d]	3.4	0.0	−3.4	0.2	0.0	−0.2	3.6	0.0	−3.6

[a] Austria, Czech Republic, Slovakia, Hungary, Serbia and Slovenia

[b] Germany, Switzerland, Denmark and Luxembourg

[c] France, Spain and Portugal

[d] Romania, Bulgaria and Greece

Table C.4: Impact of Liberalization on Stabiltiy Measures (far-sighted scenario, high intercept)

	Stability measures		
	fragmented	integrated	liberalized
$\epsilon^*(\phi, \lvert N\rvert - 1)/\sum \phi^0_{EU}$	1.5	2.1	7.6
$n^*(\phi, 0) - 1$	6	1	1
$f(\phi, \lvert N\rvert - 1, 0)$	0.0003	0.0027	0.1775

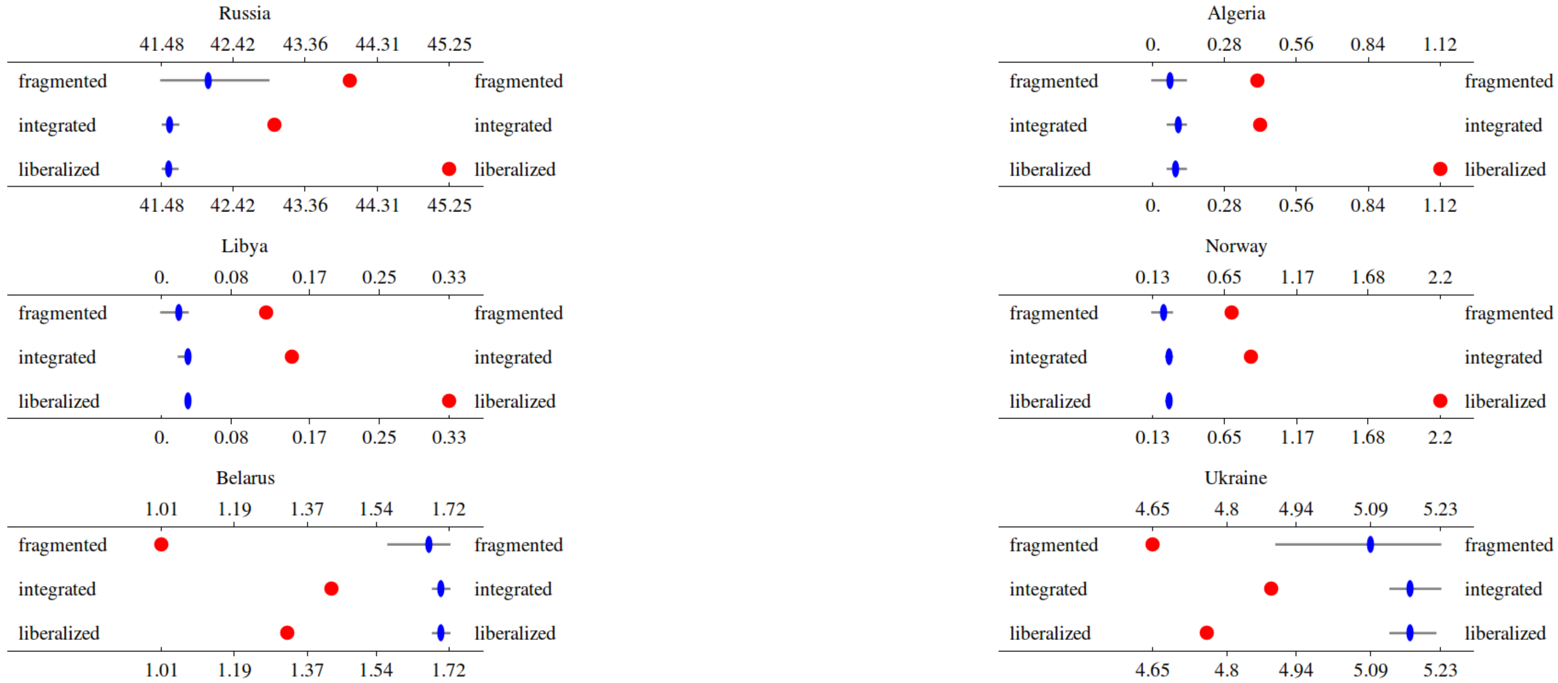
Table C.5: Impact of Liberalization on Stabiltiy Measures (short-sighted scenario, low intercept)

	Stability measures		
	fragmented	integrated	liberalized
$\epsilon^*(\phi, \lvert N\rvert - 1)/\sum \phi^0_{EU}$	1.0	1.4	7.1
$n^*(\phi, 0) - 1$	8	2	1
$f(\phi, \lvert N\rvert - 1, 0)$	0.0001	0.0011	0.0820

Table C.6: Impact of Liberalization on Stabiltiy Measures (far-sighted scenario, low intercept)

	Stability measures		
	fragmented	integrated	liberalized
$\epsilon^*(\phi, \lvert N\rvert - 1)/\sum \phi^0_{EU}$	1.0	1.2	6.6
$n^*(\phi, 0) - 1$	7	2	1
$f(\phi, \lvert N\rvert - 1, 0)$	0.0001	0.0014	0.1400

Figure C.1: Different solutions for external producers and transit countries (far-sighted scenario, high intercept)



The grey bar presents the min-max range of a player in the core. Blue elliptical disks and red circles present the nucleolus and the Shapley values, respectively. All figures are in percentage of the total surplus.

Figure C.2: Different solutions for EU champions and customers (far-sighted scenario, high intercept)

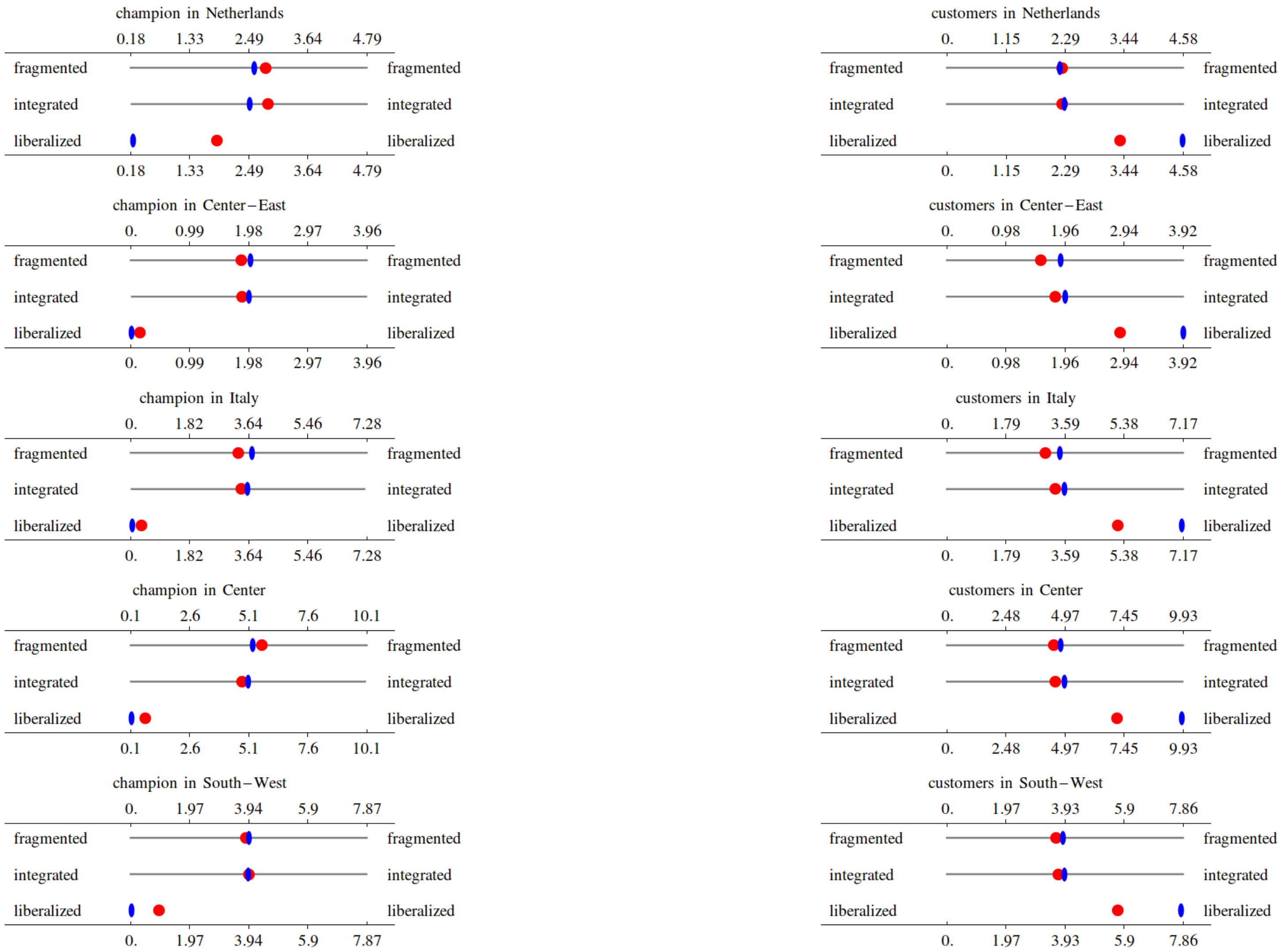


Figure C.3: Different solutions for EU regions (far-sighted scenario, high intercept)

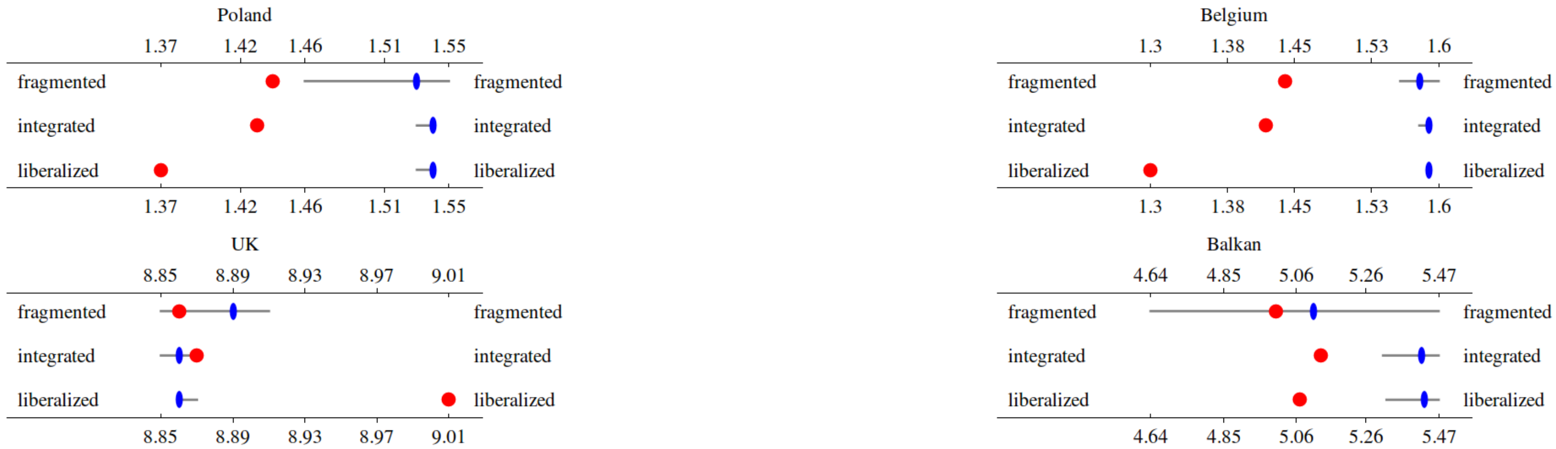
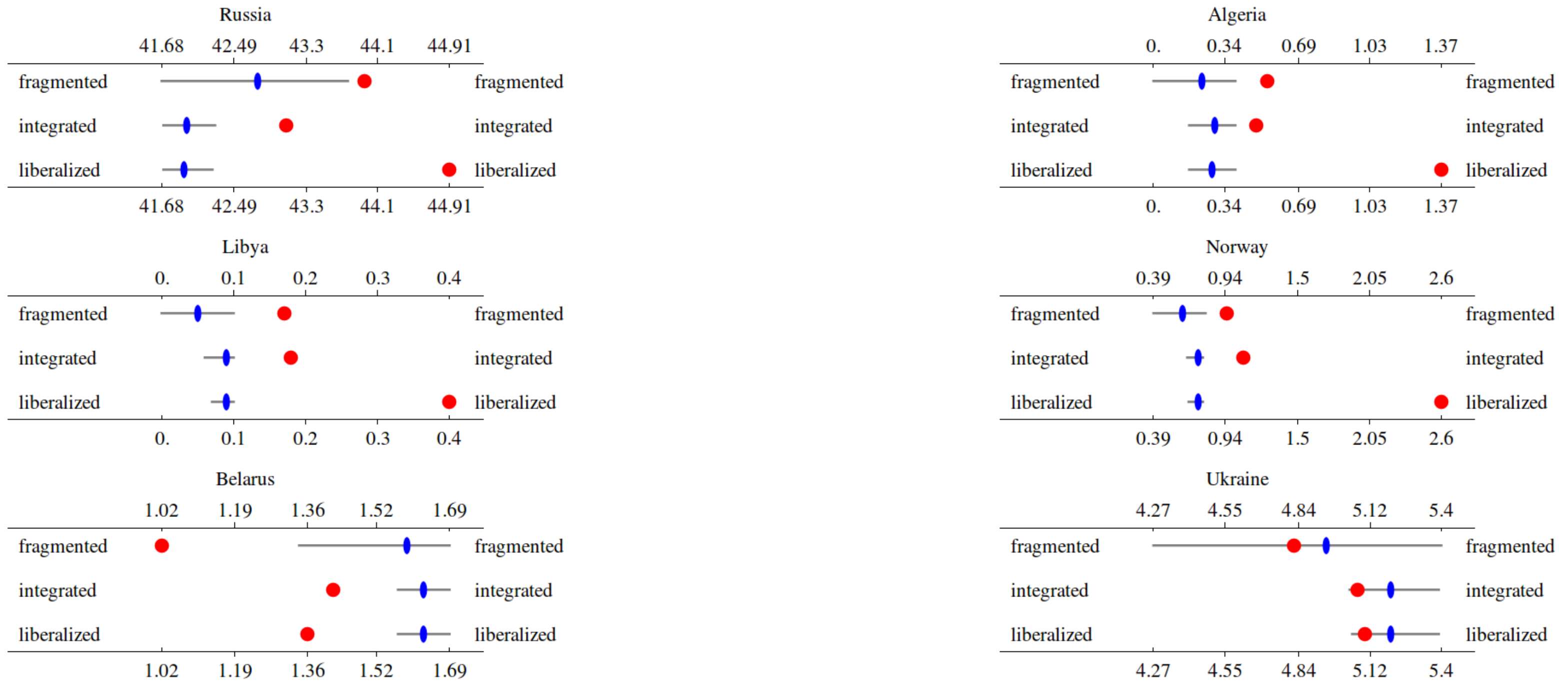


Figure C.4: Different solutions for external producers and transit countries (short-sighted scenario, low intercept)



The grey bar presents the min-max range of a player in the core. Blue elliptical disks and red circles present the nucleolus and the Shapley values, respectively. All figures are in percentage of the total surplus.

Figure C.5: Different solutions for EU champions and customers (short-sighted scenario, low intercept)

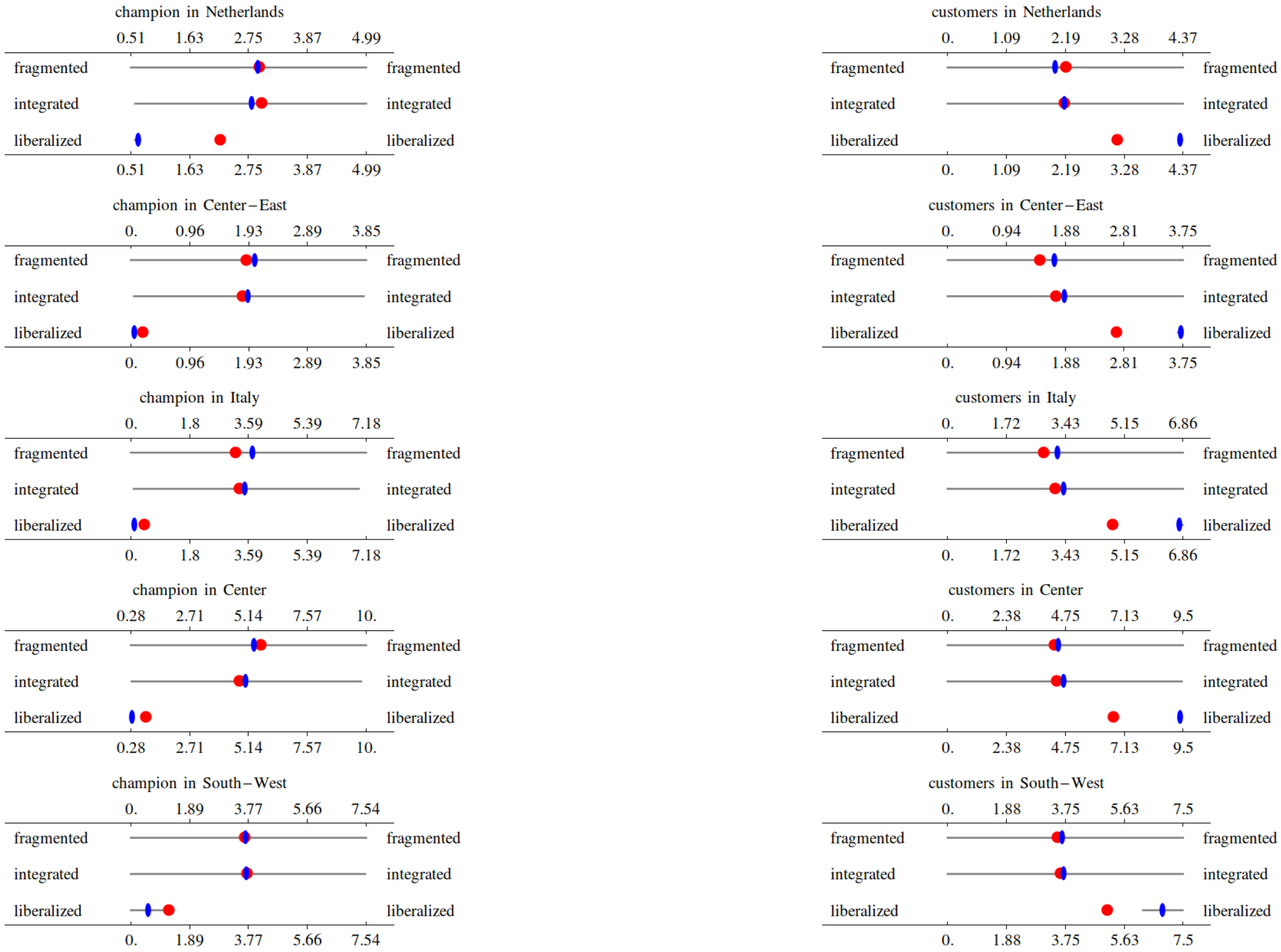
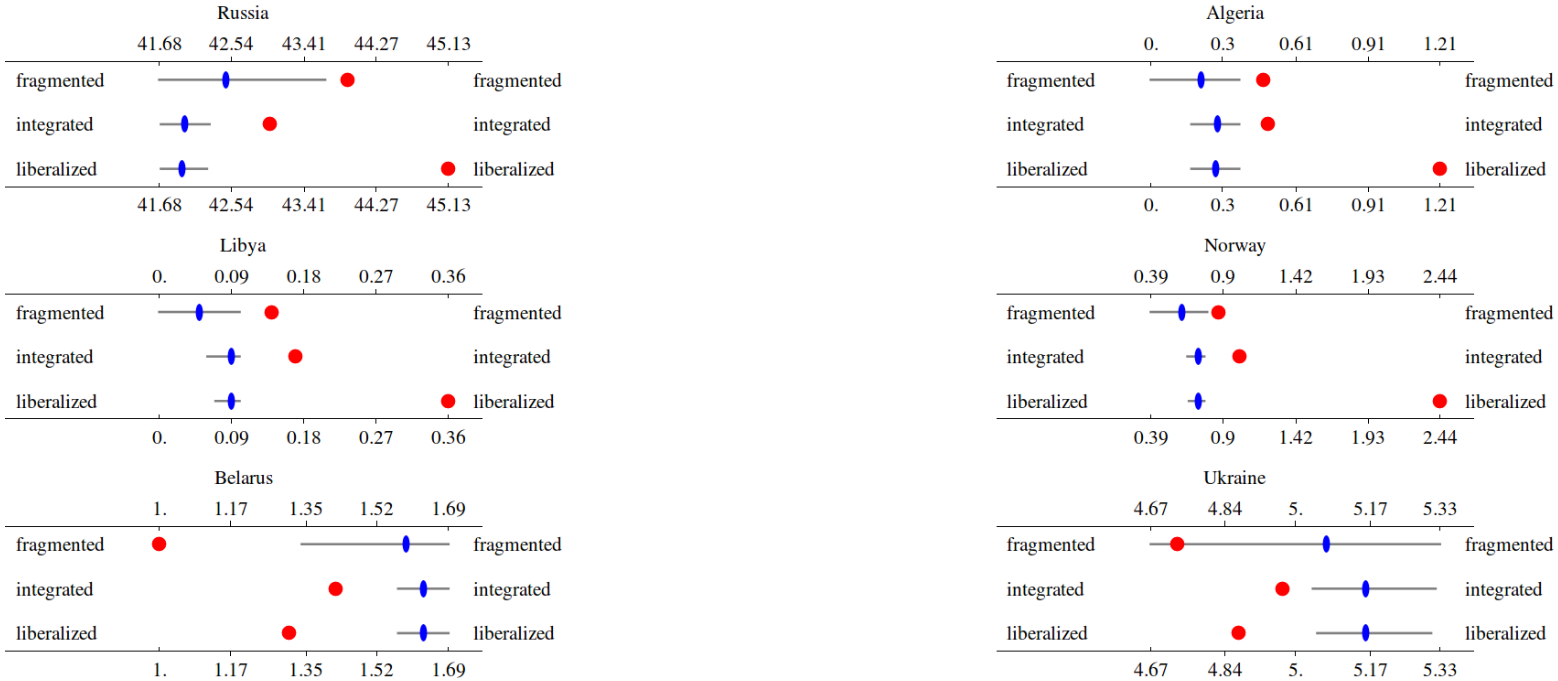


Figure C.6: Different solutions for EU regions (short-sighted scenario, low intercept)

Figure C.7: Different solutions for external producers and transit countries (far-sighted scenario, low intercept)



The grey bar presents the min-max range of a player in the core. Blue elliptical disks and red circles present the nucleolus and the Shapley values, respectively. All figures are in percentage of the total surplus.

Figure C.8: Different solutions for EU champions and customers (far-sighted scenario, low intercept)

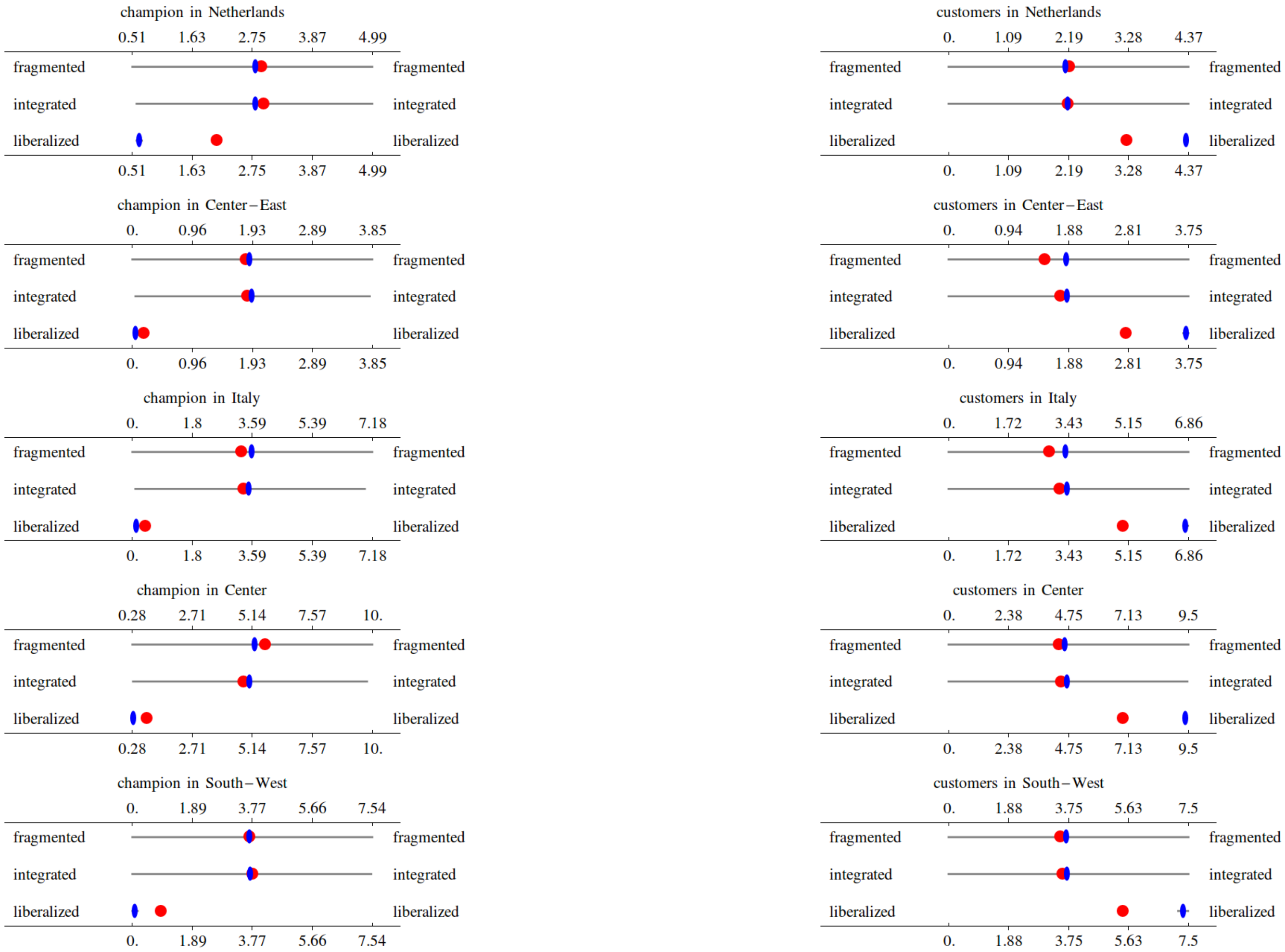


Figure C.9: Different solutions for EU regions (far-sighted scenario, low intercept)

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Appendix D

Technical Documentation

Gas Model Documentation

This technical documentation represents a joint work with Prof. Dr. Franz Hubert. Till Section D.4 the documentation is similar to the documentation presented in the dissertation of Onur Cobanli. The reason is that the papers which constitute dissertation of Onur Cobanli and the papers which constitute my dissertation share the calibrated network model.[74]

We give a documentation of the gas sector model and related calculations. Together with the data-files and the codes, available from "http://www.ms-hns.de/research_gas", it should help the reader to check and replicate the results of the following papers:

- Franz Hubert & Onur Cobanli: Pipeline Power [pipe1]
- Franz Hubert & Ekaterina Orlova: Competition or Countervailing Power for the European Gas Market [reg1]
- Franz Hubert & Ekaterina Orlova: Network Access and Market Power [reg2]
- Onur Cobanli: Central Asian Gas in Eurasian Power Game [pipe2]
- Ekaterina Orlova: Cooperative solutions for the Eurasian gas network [reg3]

[74] I would like to thank Tim Dittler, Jeldrik Hanschke and Wadim Klincov for smooth running of computer systems at Chair for Management Science. Special thanks to Jeldrik Hanschke who made it possible for our optimization routine to be calculated on each kernel of computer.

While the papers differ in their economic focus and in many technical details they all use variants of a model of the European gas-network and notions from cooperative game theory to analyze the power structure in the Eurasian gas trade. Papers start from a broad description of the network: its geographical scope, major players etc. In this respect, we have four basic variants (pipe1, pipe2, reg1, reg2); one for each paper. In the paper reg3 the same variants are used as in the paper reg2.

The papers analyze how the bargaining power of the players is affected by various changes such as a new pipeline, liberalization of pipeline access, a merger, increase of demand etc. Each of these scenarios correspond to a distinct cooperative game, for which we have a unique identifier, the *variant-name* or *VN*.[75] These games are formulated and solved using software written in Mathematica and in MATLAB. The programming packages are described in the following.

A cooperative game is characterized by a set of players N and a value function v. For each possible subset of players $S \in N$ (also called coalition), $v(S)$ gives the maximal joint payoff which the coalition S can achieve on its own. In other words, v is the result of a number of related optimization problems. These optimization problems share a common structure, because they are derived from the same broad network model, but they differ in the sense that smaller coalitions have only access to parts of the whole network.

So the analysis proceeds in four steps.

1. We characterize the general network optimization problem of the cooperative game. For each variant we specify the instruments and parameters of the network optimization problem. These parameters include the specification of access rights, so that we can derive the embedded sub-network optimization problems of smaller coalitions. We refer to this representation of the game *VN-parameters*.

2. We calculate the numerical values of the value function by solving all sub-network optimization problems for a particular variant/game. We call this representation *VN-values*. Since we look at a large set of coalitions, this step is computationally the most demanding one.

[75] Typically the variant name consists of several parts referring to specific settings such as geographic scope, set of players etc. These variant names are used as identifiers to build file names for the results (e.g. the Shapley values are saved in a file `VN-Shapley`).

3. Using the numerical value function, we calculate for each variant various solutions for cooperative games, such as Shapley value, nucleolus, core. We refer to the solutions as *VN-Shapley*, *VN-nucleolus*, etc.

4. Finally, we compare the solutions of different variants to assess the impact of pipeline investment, regulatory changes etc. and build the tables in the papers.

The code which defines the parameters of the network optimization problem, calculates the value function and then the Shapley value is written in Mathematica (step 1-3). The code which calculates the Nucleolus and the minimal and maximal values of players in the core is written in MATLAB (step 3). Further evaluations of the results are again written in Mathematica (step 4). In the next sections, we give a brief overview of the main programming tools for each of these steps.

We save results to a number of files in plain text format. The following files contain results (VN stands for variant-name).

Files containing results

name	content
description of network optimization model	
`VN-parameters-Mathematica`	The parameters for the optimization problem in the format required for `calculateValueOneCoalition[]` .
`VN-parameters-General`	Same as above in a simplified format for use with other optimization software.
value function	
`VN-value-Full`	Explicit list of coalitions and values, as well as any errors reported from the calculation (very large).
`VN-value-Mathematica`	Values in a compressed format, suitable for Mathematica's `Subsets[]` function.
`VN-value.nuc`	Values in a compressed format, suitable for calculating the Nucleolus using MATLAB code of Johannes Reijnierse.
cooperative solutions	
`VN-Shapley`	the Shapley Value
`VN-Nucleolus`	the Nucleolus
`VN-MinCore`	the minimal values players receive in the core
`VN-MaxCore`	the maximal values players receive in the core
technical files	
`VN-nucl.dat`	log and results from calculating the nucleolus.
`VN-MinCore.dat`	log and results from calculating the minimal values in the core
`VN-MaxCore.dat`	log and results from calculating the maximal values in the core

Directories

name	content
`\EAGas-model`	Mathematica notebooks and corresponding packages for setting up the network optimization problem, calculating the value function, solving for the Shapley value.
`\games+tools`	Mathematica and MATLAB code to convert files, to calculate minimal and maximal values in the core.
`\nucleolus HR`	MATLAB code provided by Hans Reijnierse for calculating the nuleolus.
`\pipe1`	special code and results related to Hubert & Cobanli: Pipeline Power
`\pipe2`	special code and results related to Cobanli: Central Asian Gas
`\reg1`	special code and results related to Hubert & Orlova: Competition or Countervailing Power
`\reg2`	special code and results related to Hubert & Orlova: Network Access and Market Power
`\reg3`	special code and results related to Orlova: Cooperative solutions for the Eurasian gas network

D.1 General Network Optimization Problem

All papers share a common data base from which the calibrations and definitions of their network optimization problems are obtained using two Mathematica notebooks, a common one `Gas Parameters` and an additional one which is individual for each paper. There are also packages to visualize the data base and the parameter settings.

All code of this section is written in Mathematica. The general network optimization problem is saved in files named `VN-parameters-*`, where the * stands for different formats.

D.1.1 Data & Calibration

D.1.1.1 Definition of data.

The data are defined in **`Gas Data Base`** using a similar format as the data provided by Mathematica. All data which are needed for the model specification and the displays (tables and maps) are assigned to global variables by loading the Mathematica package `Gas Data Base` .
requires: nothing

D.1.1.2 Visualization of data.

`Gas Data Visu` defines functions for the display of data.
requires: `Gas Data Base` , `FH Tools`

Data Overview

package	function	needs
`Gas Data Base`	assignes data to global variables	*nothing*
`Gas Data Visu`	defines functions for display of data	`Gas Data Base` `FH Tools`
file output:	*none*	

D.1.2 Set-up for network optimization

The topology of the network is defined by a set of nodes R and a set of directed links L (the geographical scope). Each link $\{i, j\} \in L$ connects two nodes, which might be

R_P production nodes, R_C consumption nodes, or R_T transit nodes.[76] For each link we have (piecewise linear) cost reflecting transportation and/or production cost.

The game is defined by a set of players N and a value function v, mapping the set of subsets of N into real numbers. A coalition $S \subseteq N$ has access to $L(S) \subseteq L$ (the access regime). The value of a coalition S is obtained by maximizing the joint surplus (gross surplus from consumption s minus cost of transportation and production T) using the gas-flows f_{ij} in the pipelines which are accessible:

$$v(S) = \max_{\{f_{ij} | \{i,j\} \in L(S)\}} \left\{ \sum_{\{i,j\} \in L(S),\, j \in R_C} s_j(f_{ij}) - \sum_{\{i,j\} \in L(S)} T_{ij}(f_{ij}) \right\} \tag{D.1}$$

subject to

$$\begin{array}{rcllr} f_{ij} & \geq & 0, & \forall\, i \in R_P \text{ or } j \in R_C & \text{(non-negativity)} \\ \sum_i f_{it} & = & \sum_j f_{tj}, & \forall\, t \in R_T(S) & \text{(balancing)} \\ |f_{ij}| & \leq & k_{ij}, & \forall\, \{i,j\} \in L(S) & \text{(capacity constraints)} \end{array}$$

The capacity constraint is dropped when we allow for investment. In this case T also accounts for investment cost.

To keep the network optimization problem simple, we assume a linear demand (quadratic surplus function) and piece-wise linear cost functions.

D.1.2.1 Definition of functions and some variants.

By loading **`Gas Parameters`** we define routines, which specify the functions and parameters of the optimization problem using the data provided by `Gas Data Base` .

The complete specification of the general network optimization problem (all the technical and demand parameters as well as the access rights) are assigned to global variables by calling: `reSetParTo[`*`parameter-list`*`]`, which in turn calls: `setGeoScope[]`, `setPlayers[]`, `setPipeAccess[]`, `setLinkParameter[]`, `setDemandParameter[]`. These routines define the geographical scope of the network, the players, the access regime, parameters for the individual links and for demand. Different (but not all) versions of these settings can be combined. `selectVarList` allows for an interactive selection of predefined arguments for the subroutines.

[76] Production and consumption nodes are always linked to a transit node.

feasiblePipes[*coalition*] returns the links to which a coalition has access.

In Gas Parameters we provide only the base variants, used in the different papers. To obtain the specific definitions for a paper, an additional file has to be loaded; e.g. Gas_Parameters pipe1.m or Gas_Parameters reg2.m. These define a unique *variant-name* (*VN*) for each network optimization (game), which will be part of the names of files for storing results etc. We also define setVar[*VN*] to return the arguments for reSetParTo[] .

parametersToFile[*VN*, "Mathematica"] saves the parameter settings of a game to a file with a name VN-parameters-Mathematica from which the settings can be recovered using fileToParameters[*VN*, "Mathematica"]. When writing "Mathematica" can be replaced by "General" to obtain a more compact format.

Gas Parameters and Gas Parameters *.m require Gas Data Base .

D.1.2.2 Visualization of parameter settings.

Gas Parameters Visu defines functions for the display of the parameter setting, once they have been assigned by calling reSetParTo[]. There are tables and maps, some of them interactive. Various functions are collected in the commands: showMainParCurrent, showAllParCurrent, which display most of the settings.

requires: Gas Data Base , Gas Data Visu , FH Tools , Gas Parameters .

D.1.2.3 Starting from defined games.

Gas Parameters min collects those routines which are needed if the parameter settings are already saved to files VN-parameters-Mathematica. If loaded, there is no need to load other notebooks.

D.1.2.4 Example.

The Mathematica notebook workspace parameters.nb illustrates these steps.

Parameters Overview

package	function	needs
`Gas Parameters`	defines functions for the assignment, saving and recovering of parameters as well as parameters for some basic variants → `reSetParTo[]` → `parameterToFile[]` → `fileToParameters[]`	`Gas Data Base`
`Gas Parameters *.m`	defines additional functions and all the variant names for the individual papers (*: pipe1, pipe2, reg1, reg2)	`Gas Data Base` `Gas Parameters`
`Gas Parameters min`	collects functions needed for recovering the parameters-settings from the file and starting the optimization	*nothing*

`Gas Parameters Visu`	defines functions for display of parameters after they have been assigned using `reSetParTo[]` .
	→ `showMainParCurrent`
	→ `showAllParCurrent`
		`Gas Data Base`
		`Gas Data Visu`
		`FH Tools`
		`Gas Parameters`

file output:	`VN-parameters-Mathematica` `VN-parameters-General`	
for illustration:	**`workspace parameters.nb`**	

→ : main functions defined in the package;   VN : variant name

D.2 Value function

Given our assumption on functional forms, we obtain the value function by maximizing surplus (quadratic) minus cost (piece-wise linear) subject to balancing constraints for transit nodes and non-negativity constraints for production and consumption links.

D.2.1 The network optimization

By loading `Gas Prog` and `Gas ProgLP` we define the functions used for solving the network optimization problem. `calculateValueOneCoalition[]` establishes the sub-network, which is accessible for a given coalition of players and calls `LinProg[]` from `Gas ProgLP` to calculate the payoff (value).

The general optimization routines coming with Mathematica turned out to be too slow. To speed up the process `LinProg[]` approximates the quadratic surplus functions by piece-wise linear functions and uses ”LinearProgramming” to solve the resulting linear optimization problem.

D.2.2 Visualization of the result

`Gas Prog Visu` defines `displayResChartLP[]`, and `displayResTableLP[]` for the display of the optimal network usage using the output created by `calculateValueOneCoalition[]` . It needs the full parameter definitions from `reSetParTo[]` and requires `Gas Data Base` , `Gas Data Visu` , `FH Tools` , `Gas Parameters` , `Gas Prog` , `Gas ProgLP` .

Network Optimization Overview

package	function	needs
`Gas Prog`	finds accessible network for a given coalition of players and calls `LinProg[]` from `Gas ProgLP` to calculate the payoff (value). → `calculateValueOneCoalition[]`	`Gas Parameters min` `Gas ProgLP`
`Gas ProgLP`	creates a linear programming problem to calculate the optimal network usage for a given network configuration. → `LinProg[]`	`Gas Parameters min`

`Gas Prog Visu`	display of the optimal network usage using output created by `calculateValueOneCoalition[]` .
	Needs parameters from `reSetParTo[]`
	→ `displayResChartLP[]`
	→ `displayResTableLP[]`
		`Gas Data Base`
		`Gas Data Visu`
		`FH Tools`
		`Gas Parameters`
		`Gas Prog`
		`Gas ProgLP`

file output:	None	
for illustration:	**`workspace program.nb`**	

→ : main functions defined in the package

D.2.3 Calculating the value function (and the Shapley value)

`Gas ValFuncShap` defines functions for the calculation of the value function. Using the unique variant-name VN we recover the parameters from the associated file `VN-parameters-Mathematica`. Then we calculate the value of all coalitions (repeatedly calling `calculateValueOneCoalition[]`). Depending on the number of players, this step may take a long time. The results are saved in two formats. `VN-values-Full` has the value, the coalition and possible error-messages and is very large. `VN-values-Mathematica` has only the numerical values ordered as the coalitions are ordered by Mathematica's `Subsets[]` command, i.e. $\{\}, \{a\}, \{b\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, \{a, b, c\}$.

As we have the value function already, it is convenient to invoke `FH Shapley` and write the Shapley value into `VN-Shapley`.

For some changes, i.e. if two players merge, it is not necessary to run all optimization problems again. The new value function can be obtained from the old one by re-matching values with coalitions. Suppose we start with a game $\{N, v\}$ and let players a and b merge. We define the new game as $\{N, w\}$ by making a a 'proxy' player and b a dummy player. The new value function w is obtained from v as[77]

$$w(S) = \begin{cases} v(S \cup b) & \text{if} \quad a \in S, \quad b \notin S \\ v(S \setminus b) & \text{if} \quad a \notin S, \quad b \in S \\ v(S) & \text{else.} \end{cases}$$

In these cases we save only the original value function.

Calculating Value Function & Shapley Value

package	does	loads

`Gas ValFuncShap`	provides operations for the calculation of the value function (which may take a long time) and all Shapley Values.
	→ `calcValFuncShap[]`
	→ `calcShapleyValue[]`
	→ `assignValueFunction[]`
		`Gas Parameters min`
		`Gas Prog`
		`Gas ProgLP`
		`FH Shapley`

file output:	`VN-value-Full`
	`VN-value-Mathematica`
	`VN-Shapley`	

for illustration:	**`workspace ValFuncShap.nb`**	

→ : main functions defined in the package ; VN : variant name

D.3 Solving the game

We consider several solutions for the games defined by the different variants: the Shapley value, the nucleolus, and the core, which we characterize by the minimal and maximal values which a player can achieve. The starting point is always the set of players and the value function as specified in `VN-value-Mathematica`.

We express the solutions as absolute values and as relative values (in per cent of the value of the Grand coalition). In addition we report the player's value when he

[77] If v is the non-normalized pre-merger value function, the stand alone value of proxy player includes also the surplus from trade between the merging parties. In order to keep the surplus in the normalized game constant, replace $w(a) = v(a \cup b)$ with $w(a) = v(a) + v(b)$.

is alone and we give the solutions (absolute and relative) for the zero normalized game.

For the calculation of nucleolus and minimal and maximal values in the core, we use MATLAB code.

D.3.1 Shapley Value

We calculate the Shapley value intermediately after calculating the value function (see section D.2.3). The function is defined in `FH Shapley` . In addition we have some tools to rearrange and aggregate players once the Shapley values are calculated.

Calculating the Shapley Value

package	does	loads
`FH Shapley`	functions to calculate the Shapley Value for a set of players and a value function. → `shapleyValue[]` → `allShapleyValues[]`	*nothing*
`FH Shapley tools`	functions to rearrange and aggregate players in the output of `FH Shapley` (or other solutions).	*nothing*
for illustration:	**`workspace ValFuncShap.nb`**	

→ : main functions defined in the package

D.3.2 Nucleolus

To calculate the nucleolus we use MATLAB code provided by Hans Reijnierse. It implements an algorithm described in Potters, J. A.; Reijnierse, J. H.; Ansing, M. (1996): Computing the Nucleolus by Solving a Prolonged Simplex Algorithm, *Mathematics of Operation Research*, 21(3), 757-68. The algorithm in turn is based on the characterization of the nucleolus as the lexicographical center of the game developed in Maschler, M.; Peleg, B. Shapley, L. S. (1979): Geometric Properties of the Kernel, Nucleolus, and Related Solution Concepts, *Mathematics of Operation Research*, 4(4), 303-38.

We first convert `VN-value-Full` into `VN-value.nuc`. This file is used by MATLAB program `calcNucleolus`, which invokes Reijnierse's command "nucleolus". The log and results are written into `VN-nucl.dat`. We switch back to Mathematica code to further process `VN-nucl.dat`, extracting the nucleolus and those coalitions and their excesses which determine the solution.

Calculating the Nucleolus

package	does	loads
`convert-nucleolus`	Preparing input for MATLAB, reading MATLAB output and writing it to files. Convert `VN-value-Full` into `VN-value.nuc`, extract results from `VN-nucl.dat` (MATLAB output) into Mathematica, and prepare the input for the tables. → `writeMatlabInputFunc[]` → `vectorNucleolusList[]` → `vectorPlayersNucleolus[]` → `writeToFileAllValues[]`	*nothing*
`calcNucleolus` (MATLAB)	Reads `VN-value.nuc`, calculates the nucleolus, writes `VN-nucl.dat`.	`nucleolus`
`nucleolus` (MATLAB)	package to calculate the nucleolus written by Potters, Reijnierse, Ansing (1996).	

file output:	`VN-value.nuc`
	`VN-nucl.dat` (from MATLAB)
	`VN-Nucleolus`	

for illustration:	**`workspace nucleolus.nb`** **`workStepsNucleolus.nb`**	

→ : main functions defined in the package ; VN : variant name

D.3.3 Core

As the core is characterized by a large number of inequalities, we restrict attention to the extreme values which a player can obtain in the core. For each player we find the minimal and the maximal value in core.

As with the nucleolus we use MATLAB to compute the values.

Characterizing the Core

package	does	loads
`convert-core`	collects routines for creating matrices and writing "*.csv" files for optimization in MATLAB. We also define functions to extract the values from MATLAB output files, to compare these values with the nucleolus and the Shapley value, to prepare the input for the tables. → `writeMatricesVariantsMatlab[]` → `readMatlabCore[]` → `ShapleyMinNuclMax[]` → `writeConceptsToFile[]`	`convert-nucleolus`
`calcMaxMinCore` (MATLAB)	Reads `variants.csv`, `matrices.csv` and `VN_matrixname.csv`, calculates the minimum and the maximum for each player, writes `VN-MinCore.dat` and `VN-MaxCore.dat`.	*nothing*

file output:	`VN_matrixname.csv`
	`variants.csv`
	`matrices.csv`
	`VN-MinCore.dat` (from MATLAB)
	`VN-MaxCore.dat` (from MATLAB)
	`VN-MinCore`
	`VN-MaxCore`
	`VN-Concepts`	

for illustration:	**`workspace core.nb`** **`workStepsCore.nb`**	

→ : main functions defined in the package ; VN : variant name

D.4 Special packages for paper 1 [reg1]

D.4.1 Mergers

We study incentives for mergers in the fragmented and integrated markets using the Shapley value concept. The package `Gas Mergers` defines routines to calculate the value function in case of collusion and to compute the effect of a merger on the power structure.

When we assume that Center region is 'proxy' player, we write the post-merger Shapley values to a file with the following naming convention: `VN-the name of the last player among dummy players-Merge`. Hence, the name of the file contains information about the merging parties. To report the impact of mergers with Center region on the power structure in the table, we prepare the input for the table using the files with the pre-merger and post-merger Shapley values (see package `TabTools Reg1` in the next subsection).

To analyze the effect of a merger on non-colluding players, we follow approach of Segal (2003). We present the difference between the Shapley values of non-merging players as the sum of weighted third-order differences. The weighted third-order differences and the respective coalitions are written to a file `Player-Dummy-thirdOrderDiff-shortVN`. We provide also the graphical represenation of third-order differences. `Gas Mergers` defines the respective routines.

To consider the impact of all pairwise mergers on the power structure, we write the differences between the respective Shapley values to a file with the naming convention `VN-AllMergers`.

Mergers: Calculating Value Function, Shapley Values and Impact

package	does	loads

`Gas Mergers`	routines to calculate the value function in case of collusion, to write respective Shapley values to a file, functions to study the impact of a player on 'complementarity' of merging parties, functions to find the effect of all pairwise mergers on outside producers.
	→ `writeShapNormCollusion[]`
	→ `complementarity[]`
	→ `writePairwiseMergersToFile[]`
	→ `tableProfitability[]`
	→ `tablePairwiseMergers[]`
	→ `dispComparedResultsMergers[]`
		`Gas Data Base`
		`Gas Data Visu`
		`Gas Parameters`
		`Gas Parameters Reg1`
		`Gas Parameters Visu`
		`Gas Prog`
		`Gas ProgLP`
		`Gas Prog Visu`
		`Gas ValFuncShap`
		`FH Shapley`
		`FH Shapley tools`
		`FH Tools`

file output:	`VN-dummyPlayerName-Merge`
	`VN-AllMergers`
	`Player-Dummy-thirdOrderDiff-shortVN`	

for illustration:	**`workspace mergers.nb`**	

→ : main functions defined in the package ; VN : variant name

D.4.2 Tables

Here we define routines to create tables for the paper reg1.

Creating the Tables

package	does	loads
`Gas TabTools`	defines the functions to add the players to the list of values for a concept and to find the difference between the given values for any two variants → `addPlayers[]` → `diffValues[]`	`FH Shapley tools`

Creating the Tables

package	does	loads
TabTools Reg1	collects routines to create the tables for the paper reg1 → tableBenchmark[] → tableImpact[] → tableCartel[] → tableMergers[]	FH Shapley tools FH Tools Gas TabTools
file output:	none	
for illustration:	**workspace tablesReg1.nb**	

→ : main functions defined in the package

D.5 Special packages for paper 2 [reg2]

D.5.1 Tables

Here we define routines to create tables for the paper reg2.

Creating the Tables

package	does	loads
TabTools Reg2	collects routines to create the tables for the paper reg2 → shareOfRedistributedAmount[] → tableLiberalization[] → tableRange[]	FH Shapley tools FH Tools Gas TabTools Gas Parameters Gas Parameters Reg2
file output:	none	
for illustration:	**workspace tablesReg2.nb**	

→ : main functions defined in the package

D.6 Special packages for paper 3 [reg3]

Here we present the packages which are used to relate the Shapley value and the nucleolus to the core. The packages are written to analyze the compression of the core, to compute the stability measures and to create the tables and graphs for the paper ”Cooperative solutions for the Eurasian gas network”.

D.6.1 Compression of the Core

for Sections 3.3, 3.4 and 3.5

package	does	loads
`ToolsForPart3`	defines general functions which are used in other packages → `getConcepts[]` → `distance[]` → `createAssignments[]`	*nothing*

`CoreCompression`	defines the functions to present the impact of liberalization on the core, to compare the computed maximal values of players in the core with the respective contributions to the grand coalition, to compare the minimal values with the respective stand alone values, and defines the function to find the binding constraints
	→ `tableCoreRedistr[]`
	→ `tabExplainMaxCore[]`
	→ `tabExplainMinCore[]`
	→ `findBindingConstraints[]`
		`convert-nucleolus`
		`convert-core`
		`Gas ValFuncShap`
		`FH Shapley tools`
		`FH Tools`
		`ToolsForPart3`

`RelateNuclCore`	collects routines to create the tables, which are used to relate the nucleolus and the core (e.g., functions to determine the location of the nucleolus in the min-max range, the shift of the midpoint and the nucleolus) → `tabAbsChangeMinMaxRange[]` → `tabLocationNuclInRange[]` → `tabShiftNuclMidRangeRelative[]`	`ToolsForPart3`
`graphsConcepts`	collects routines to create the graphs for comparison of the concepts with respect to the power allocation → `graphsPowerAllocation[]`	`FH Shapley tools` `FH Tools`

	for Sections 3.3, 3.4 and 3.5
file output:	`none`
for illustration:	**`workspace CoreCompression.nb`** **`workspace NuclCore.nb`** **`workspace graphsConcepts.nb`**

→ : main functions defined in the package

D.6.2 Stability Measures

The function `stabilityMeasures[]` allows us to assess the degree of instability of the Shapley value as described in the text of the paper reg3. Deviating coalitions are found given the assumption that setting up a coalition of any size would not cost anything. Deviating coalitions are written to a file with the naming convention: `VN-deviatingCoalitions`.

for Section 3.6

package	does	loads

`StabilityMeasures`	defines the functions which are used to compute the three stability measures for each market structure
	→ `stabilityMeasures[]`
		`Gas ValFuncShap`
		`FH Shapley tools`
		`FH Tools`
		`ToolsForPart3`

file output:	`VN-deviatingCoalitions`	
for illustration:	**`workspace StabMeasures.nb`**	

→ : main functions defined in the package ;   VN : variant name

Declaration

Ich bezeuge durch meine Unterschrift, dass meine Angaben über die bei der Abfassung meiner Dissertation benutzten Hilfsmittel, über die mir zuteil gewordene Hilfe sowie über frühere Begutachtungen meiner Dissertation in jeder Hinsicht der Wahrheit entsprechen.

Berlin, 18.12.2014 Ekaterina Orlova